ABSTRACT

Title of Dissertation: MODELING THE PULMONARY EFFECTS OF RESPIRATORY PROTECTIVE MASKS DURING PHYSICAL ACTIVITY

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Current respirator design involves developing and testing a prototype, making modifications, and then re-testing until a suitable mask is obtained. If the physiological effects of the respirator could be modeled, design could proceed more rapidly. Such a model would be an important design tool that would provide valuable information on the potential physiological and psychological compatibility of a respirator with the wearer. The model would not eliminate the need for human testing, but would decrease the number of prototypes required, saving time and money.

A successful model would be very complex because of the many factors to consider. And, because of the variability of human response to exercise, work, and respirator wear, the initial development of the model will include many assumptions that may limit the expected accuracy of the predictions.

The goal of this research was to develop a model of the pulmonary effects of respirator wear during physical activity that would form the framework of a larger model that would include other factors as well. Empirical equations were developed that related oxygen consumption to physiological work rate, anaerobic threshold, minute ventilation and tidal volume to oxygen consumption, and exhalation time to respiratory period. Respirator resistance and dead volume effects were quantified. The model was implemented in Visual BASIC.

The model predicted oxygen consumption, minute ventilation, and tidal volume well for a limited number of subjects exercising below 70% of maximal oxygen consumption. For three subjects wearing respirators and exercising at 80-85%, the errors in the model parameters were greater than those of the original equations. As model equations were based on average responses, predictions for any one individual may have large errors. Model simulations of a subject exercising at five different work rates with and without a respirator showed that the model made rational predictions of the effects of a respirator on respiratory parameters. More data is needed to completely validate the model. These results showed that the model structure was valid and that overall the model was capable of making rational predictions of the average effects of respirator wear on pulmonary system parameters during physical activity.

MODELING THE PULMONARY EFFECTS OF RESPIRATORY PROTECTIVE MASKS DURING PHYSICAL ACTIVITY

by

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2001

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DEDICATION

This dissertation is dedicated to my parents, Thomas L. and the late M. Eleanor Coyne, with thanks for their love, encouragement, and support.

ACKNOWLEDGEMENTS

There were many people who aided in the completion of this degree. I would like to thank my advisor, Dr. Arthur Johnson, for all his encouragement, support, and advice along the way. I am grateful to my other committee members, Dr. Marc Rogers, Dr. Gerald Saidel, Dr. Paul Schreuders, and Dr. Adel Shirmohammadi, for their advice and guidance with this research. I would like to thank my subjects for volunteering for my study and Mr. William Scott for helping with all the testing. I would like to thank the staff of the ENBE department for working behind the scenes to see that I received my paychecks, got my numerous forms completed, and made all the deadlines. My thanks to my fellow graduate students for their moral support, friendship, and pep talks. A special thanks to my great friend Ellen DeRico for being there over the years through the good times and the bad, for laughing with me and crying with me, and for sharing the many frustrations (darn text boxes!) involved in pursuing two degrees. And finally, my thanks to my family for their love, moral and financial support, and patience especially over the last few months. Thanks to my brothers, Kevin and Patrick, for scanning documents and typing references and to my Dad for playing chauffeur. Thanks to my nephew, Andrew, and my niece, Carly, for their hugs and smiles. A special thanks to Carly, for helping me with my "homework" even though we weren't in the same grade. Thanks for reminding me that learning is supposed to be fun.

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INTRODUCTION

The need to protect workers from the inhalation of airborne contaminants has been recognized for many centuries. In 77 AD, Pliny the Elder wrote about red lead refiners wearing animal bladders to avoid breathing the lead dust (Roach, 1992). People such as Leonardo da Vinci (1452 - 1519) and Bernardino Ramazzini (1633 - 1714) recognized also the need for respiratory protection (Rajhans and Blackwell, 1985). However, it wasn't until the 1800s and the industrial revolution that significant advances were made. In 1814, the "precursor to the modern day air-purifying respirator was developed" and in 1825, John Roberts developed a smoke filter for firefighters (Rajhans and Blackwell, 1985). In 1910, the Mine Enforcement Safety Administration (MESA), the predecessor of the Mine Safety and Health Administration (MSHA), began specifying regulations about the design and certification of different respiratory protection sold in the United States (Teresinski and Cheremisinoff, 1983). Design progressed rapidly during WWI when toxic gases were first used as a military weapon (Rajhans and Blackwell, 1985).

In 1970, the concern for worker health came to the forefront. Former Labor Secretary Schultz testified before Congress that 14,500 Americans died and 2.2 million workers were disabled due to industrial accidents each year and, the U. S. Public Health Service stated that there were approximately 390,000 new cases of occupational diseases each year (Wang, 1993). The total monetary cost to the American public was estimated at $8 billion annually. Due to the large numbers of workers killed or injured in industrial accidents every year, the Williams and Steiger Occupational Safety and Health Act (OSHA) was enacted in 1970. OSHA made employers responsible for the safety and health of their workers in the workplace. Engineering controls, such as increased ventilation, should be used first in protecting against the health risks from hazardous substances in the workplace. When these controls fail or are not technically feasible, personal protective equipment becomes necessary.

Respirator masks are an essential component of the personal protective equipment and are used to protect workers against the inhalation of various contaminants - dust, mist, vapor, gas, and fume – that are found in the manufacture of chemicals, automobiles, steel, batteries, furniture, adhesives, and many other products. Additionally, there are individuals in small factories, offices and laboratories who are exposed to hazardous substances. Painters, soldiers, firefighters, miners, wood workers, construction workers, asbestos removal personnel and others must wear these masks. These workers perform activities of a physical nature at varying intensities while wearing respirators.

Respirator design currently involves making a prototype and then testing it on humans. Adjustments to the respirator are made based on those tests and then a new prototype is made and is tested. This process continues until an adequate respirator is developed. A model that predicts the effects of a respirator on a person would allow respirator design to proceed more rapidly. Such a model would be an important design tool that would provide valuable information on the potential physiological and psychological compatibility of a respirator with the wearer. The model would not eliminate the need for human testing, but would decrease the number of prototypes and testing required. Much time and money could be saved.

There are thermal, metabolic, cardiovascular, respiratory, and psychological effects of respirator wear that need to be considered. Information on these effects is found in many different sources. A model would bring this information together and quantify these effects. The development of the model should also indicate areas where more information is necessary.

A successful model would be very complex because of the many factors to consider. And, because of the variability of human response to exercise, work, and respirator wear, the initial development of the model will include many assumptions and this may limit the expected accuracy of the predictions. As more research is done that quantifies the effects of respirators on humans, this information should be included in the model.

The purpose of this research was to develop a model that examined the effects of a respiratory protective mask on the pulmonary system during constant-rate exercise. This model could form the foundation for the larger model. If the intensity is not severe, constant-rate exercise will eventually result in a physiological steady-state (Wasserman et al. 1967; Poole and Richardson, 1997). Although a steady-state may not be possible physiologically, parameter values may still be determined because these steady-state values will determine the rate of rise of the parameter and will be important when transient effects are included (Givoni and Goldman, 1972).

REVIEW OF LITERATURE

When investigating the behavior of large-scale biological systems, it is often difficult to determine the effect changes in the system parameters have on the overall system. This difficulty may be due to the scale of the system or to problems collecting data. To overcome these problems, a mathematical model of the system may be developed. "[Mathematical models] provide a concise description of complex dynamic processes, indicate ways in which improved experimental design could be achieved and enable hypotheses to be tested (Finkelstein and Carson, 1985)." This approach has become more common in recent times due to the increase in the computational power of computers and the use of the systems approach to problem solving (Murthy et al., 1990).

A model is a representation of a system in the real world. This system is analyzed to determine the important components and interactions between these components. These observations are then translated into a set of mathematical equations that describe the relationships between a system's behavior and its properties (Finkelstein and Carson, 1985). The resultant model is only an approximation of the whole system. The degree to which the model corresponds to the real-world system will depend on the purpose for which the model is designed. If a great degree of accuracy is required, the model necessarily becomes more complex and subsequently more difficult to evaluate. A less complex model would be simpler to evaluate, but would contain less information.

Developing mathematical models is not just a science, it is an art as well (Finkelstein and Carson, 1985; Murthy et al., 1990). Science is evident in the principles and equations used to formulate the model. However, artistic aspects such as creativity, ingenuity, intuition, and foresight are needed to make the model more than just a group of related equations. Because of the degree of personal choice in specifying a model, no two models will be the same.

Model Development

Model development depends in part on the type of model being used. Mathematical models may be classified as either empirical or theoretical, although there may be an overlap between the two (Murthy et al., 1990; Shirmohammadi et al., 2001). A theoretical model results when well-established theories are used in determining the equations for a model. These models are called also physical or mechanistic models because they are based on the physical system. When the modeler fits equations to a set of data without considering the theory behind the relationship, an empirical model results. However, even when an empirical model is developed, it is important that the model not contradict established theory. So, an empirical model does have some theoretical basis. Theoretical or physical models have a broader application than empirical models because the theoretical models are not based on any one data set (Shirmohammadi et al, 2001).

In developing a model, it is important that a systematic approach be used. While various authors (Finkelstein and Carson, 1985; Hunt, 1999; McCuen, 1993; Murthy et al., 1990) use different nomenclature to describe the modeling process, the approach should involve the following steps: problem formulation, factor specification, data collection, assumption making, system characterization and mathematical description, model formulation, model calibration, and model validation. Because each of the stages is interrelated, the overall process is inherently iterative (Finkelstein and Carson, 1985).

The techniques of aggregation, abstraction, and idealization must be employed during each stage of model development (Finkelstein and Carson, 1985). Aggregation involves grouping many common objects into one composite object. For example, the resistances of the arteries in the leg may be considered as a circuit of many single resistances or as one lumped equivalent resistance. The choice would depend on the intended use of the model. Abstraction concerns the "degree to which only certain aspects of a system are included in a model (Finkelstein and Carson, 1985)." For instance, a model of stream health may include industrial pollution but not surface runoff. Approximation of system characteristics, or idealization, is also performed. An example of idealization would be assuming that all gases in a system are mixed instantaneously, even though this takes some finite time to occur.

Problem Formulation

The problem formulation stage involves determining the objectives or purpose and scope of the model. It is important that the purpose be stated explicitly with as much detail as possible because the form of the model will depend on the purpose. "Thus the form of a model which is simply being used to describe some experimental test data is unlikely to be the same as one used for examining alternative hypotheses regarding the precise quantitative nature of the chemical and neural control of breathing or as that used for predicting the growth of a dysmature infant in response to a particular regime of feeding (Finkelstein and Carson, 1985)."

Models may be developed to be descriptive, predictive, or explanatory (Finkelstein and Carson, 1985). Descriptive models attempt to find relationships between data. An example would be determining the equation relating the change in heart rate at increasing levels of exercise to the work rate. Predictive models are used to determine how a system will respond to a stimulus or change in the system, for example to predict the response of a person to a new drug. Finally, explanatory models provide insight into "the ways in which different features of system behavior and structure depend upon each other (Finkelstein and Carson, 1985)." Many models are a combination of the three.

Factor Specification

At this stage it is important to list all the important factors in the model. Simplification and elimination of some factors will occur later. Factors can be classified into three categories (Edwards and Hamson, 1990): constants, parameters, and variables. Constants are factors that have fixed values (speed of light) and factors that are essentially the same in all cases of interest (acceleration due to gravity). Parameters have constant values for a particular problem but can change from problem to problem (Edwards and Hamson, 1990). In a fluid pumping model, the fluid density, the pipe diameters, and the pipe lengths would all be parameters. While these factors may vary from system to system, they are constant for the particular system being investigated. Variables will have values that change throughout the model. For the fluid pumping system, the velocity of the flow in the pipes would be a variable because its value will change depending on factors such as the pipe diameter.

After listing all the possible factors, it is useful to group related factors together (Edwards and Hamson, 1990). This will help later when relationships between factors are formed. Each of the factors needs to be identified as a constant, parameter, or variable. Variables should then be divided into inputs and outputs. It is often easiest to first identify the constants and parameters and then the variables can be separated. To distinguish between input and output variables, it is helpful to look at the possible relationships between factors in each group. If a variable is a direct consequence of other variables, then that variable is an output (Edwards and Hamson, 1990). If a variable's value is independent of all other variables, then that variable is an input to the model. To complete the list, each factor should be assigned a variable name and units.

Data Collection

Data concerning and knowledge about the various factors involved in the model must be obtained. This information helps to define the scope of the model and may also cause the objectives to be altered if, for instance, there is not enough information available. The required data may be available from various reference sources or new experiments may need to be conducted to obtain the data.

Data are necessary for many stages of the modeling process. Plotted data can give insight into the mathematical form of a model or part of the model. Data are used in the calibration stage to approximate model parameters. They are used also in the validation stage to determine whether the model results agree adequately with real situations.

System Characterization and Mathematical Description

Because the model is only an approximation of the actual system, the modeler must decide which "features or characteristics of the system are relevant and significant for the goal in mind (Murthy et al, 1990)." The systems approach requires first a functional and then a mathematical description of the biological processes and systems involved. The degree of detail included in a model is a compromise and is a part of the art aspect of modeling (Murthy et al., 1990). Including too much detail results in a cumbersome model, while having too little detail gives an incomplete model.

The relationships between the factors must next be specified. This involves deriving equations based on the gathered data. In many cases, such equations already exist. The modeler then must choose which equations fit the particular problem. In later stages, it may be necessary to return to this point to either include more information or eliminate some factors.

The end result of this stage is a collection of equations describing the procedures and processes that characterize the system. This collection is still far from being a model. It is during the next stage that these equations are combined and formed into a model.

Model Formulation

An inductive, deductive, or pragmatic approach is used in formulating a mathematical model. The inductive approach involves observing system behavior and trying to model its characteristics. With this method, it is unlikely that the model parameters will have any physical significance. The deductive approach breaks a large system down into its component parts. Equations are developed for each of the parts and for the interaction between the parts. A model is then formed from this system of equations (Barreto and Lefevre, 1984). The engineering approach is frequently the pragmatic one. That is, the model is determined with a definite purpose in mind (Barreto and Lefevre, 1984). Physiological models typically use the deductive method because of the need to understand each of the parts and its relationship to the whole system.

These approaches lead to empirical and theoretical models, or to combinations of the two. An empirical model results when an inductive approach is used. These models are typically viewed as "black boxes" because the resultant model is based only on the data, not on any theory or knowledge about the system. Empirical models are generally used only for descriptive purposes.

The deductive approach leads to a theoretical model. This type of model is based on *a priori* knowledge about the system's structure and function. These models can be used for descriptive or predictive purposes.

If the deductive approach is used, it is necessary to couple together the individual equations determined in the system characterization stage. This process is not as simple as connecting the equations together. Care must be taken that the resultant model is not redundant and does not contain any incompatibilities such as two voltage sources connected in parallel (Barreto and Lefevre, 1984). Once the model has been formed by relating the equations, the model must then be evaluated.

Calibration

The next step in the model development is to calibrate the model. This involves fitting the model to the data by adjusting the coefficients of the predictor, or independent, variables, so that accurate model output is obtained. The values of the coefficients that give the best agreement between the model output and collected data are considered the optimal values (McCuen, 1993). In addition to the model itself, an objective function and a set of measured data are needed to calibrate the model. The objective function is an explicit mathematical function that specifies the optimal solution. Often, the least squares fit of a model is used as the objective function.

Not all of the data should be used for calibrating the model. Some of the data should be saved for the next stage, model validation.

Validation

Validation consists of assessing whether the model is accurate and achieves the purpose for which it was designed. It is not possible to verify a model. "[Models] are essentially hypotheses, which are tested by subjecting them to crucial experiments designed to falsify them and they are accepted to the extent that they are not falsified. (Finkelstein and Carson, 1985)." Validity concerns not just the final output, but the purpose, current theories, experimental test data, and other relevant knowledge (Finkelstein and Carson, 1985). When new theories are accepted and more experimental data are obtained, the model must be validated again.

Validation of the model should take place throughout the development of the model, not just at the end. If any validation assessment indicates errors or inaccuracies in the model, it is necessary to return to the system characterization and formulation stages to make changes. It may even be necessary to modify the initial conceptual model (Finkelstein and Carson, 1985).

If it is not possible to validate the completed model, then model reduction must be used. This process begins by reviewing the initial conceptual model. Systematic model reduction is then accomplished by making assumptions based on physiological and mathematical principles (Finkelstein and Carson, 1985). Although it may seem better to start with this simplified model, "there is the danger, particularly if the model is formulated simply on the basis of conforming to test response data, that it will lack physiological realism (Finkelstein and Carson, 1985)."

Determining the level of acceptance of the model and the degree to which the model replicates experimental data is subjective and often determined by the model purpose. Specifying the validation criteria explicitly will reduce this subjectivity (Cobelli et al., 1984).

The validity of a model is assessed using both internal and external criteria (Finkelstein and Carson, 1985). Internal criteria include consistency and algorithmic validity. The model is considered to be consistent if it does not have any mathematical, logical, or conceptual contradictions (Finkelstein and Carson, 1985; Cobelli et al., 1984). Algorithmic validity requires that the algorithm be appropriate for the model and that it lead to accurate and logical solutions (Finkelstein and Carson, 1984; Cobelli et al., 1984).

External criteria include empirical, theoretical, pragmatic, and heuristic validity. Empirical and theoretical validity concern current knowledge. The model is empirically correct if it agrees with experimental data and is theoretically correct if it follows currently accepted theories. Pragmatic validity assesses whether or not the objectives of the model have been met. Heuristic validity concerns determining the "potential of the model for scientific explanation, discovery, and hypothesis testing (Finkelstein and Carson, 1985)."

Methods of Validation

No model should be used before it has been validated thoroughly. Validation consists of assessing whether the model is accurate and achieves the purpose for which it was designed. The model is subjected to input data over the range expected in the physical system to ensure that rational output is obtained. However, it is not possible to verify a model. The model is accepted to the extent that it cannot be proven incorrect.

Both qualitative and quantitative methods are used to assess empirical and theoretical validity. Care must be taken when using any validation method. No single method should be used to determine validity. A combination of qualitative and quantitative methods should be performed with the results being used in conjunction with knowledge, experience, and common sense to determine the validity of the model.

Qualitative Analysis. Qualitative assessment consists primarily of observing the output response and comparing it to the expected response. Such parameters as magnitude and sign of the output should be checked to determine if they are physiologically reasonable. Trends in the data, such as expected increases and decreases in the output should also be checked.

Quantitative Analysis. Quantitative evaluation generally involves goodness-of-fit tests to determine how closely the model output agrees with experimental data. The correlation coefficient, modified correlation coefficient, and standard error of estimate can all be used. In many cases, including time-dependent models, these goodness-of-fit criteria should be considered goodness-of-fit indices and not statistical measures because the underlying statistical assumptions, such as independent observations of the data, do not hold. The indices are still measures of variance, but "they should not be used with standard tests of significance (McCuen, 1993)."

However, Finkelstein and Carson (1985) argue that "due to the considerable physiological variation within the human population and the errors involved in measurements on the cardiovascular system, it is not appropriate to use integral of error squared or other similar performance criteria in the comparison of this model with the real cardiovascular system." They recommend feature matching of the principle responses as the primary validation procedure. Murthy et al. (1990) state that goodness of fit tests can be used if they are adapted to the particular evaluation and have suggested specifying individual indices for each part of the model to be validated.

The approach of McCuen (1993) is more practical. Seven criteria are described that should be considered when assessing a model's reliability; not all seven should be used with all models. These criteria are coefficient rationality, meeting the assumptions of the model, standard error of the estimate, correlation coefficient, model and relative bias, accuracy of fitted coefficients, and the analysis of variance (McCuen, 1993).

Model rationality concerns both whether the output is reasonable and whether the coefficients provide an accurate relationship between the predictor and criterion variables. All coefficients should be rational in sign and magnitude. The intercept coefficient has the same units as the dependent variable so its rationality can be assessed directly. However, slope coefficients have units that are a function of both the independent variable and the dependent variable. Slope coefficients may be converted to dimensionless standardized partial regression coefficients:

$$t_i = \frac{b_i S_i}{S_y} \tag{1}$$

where: b_i is the slope coefficient

S_i is the standard deviation of predictor variable i

S_y is the standard deviation of the criterion variable.

A standardized partial regression coefficient has an absolute value between one and zero, with one indicating an important predictor variable. If the absolute value exceeds one, then intercorrelations are significant and the coefficient is irrational. McCuen (1993) stated that an irrational model should be used with caution and should not be used beyond the range over which it was developed.

The model bias is found by summing the differences between the model and experimental values. A positive bias means that the model consistently overestimates, while a negative bias indicates the opposite. Small biases are tolerable if other criteria are met. The t-test can be used to determine if model bias is significantly different from zero.

The standard deviation is a measure of the spread of the data and the accuracy of the mean. To reduce the error variance, the criterion variable is related to the predictor variables. The goal is to provide an unbiased relationship that has a minimum sum square of errors. The error variance is the sum square of errors divided by the degrees of freedom. The standard error of estimate is the square root of the error variance. If the S_e is less than the S_y of the population, then the model provides a better estimate of the criterion variable than the mean. The ratio, S_e/S_y, is used to determine if any improvement has occurred. If the ratio is near zero, a significant improvement has occurred. Conversely, if the ratio nears one, no improvement has occurred.

The correlation coefficient is a measure of the degree of the relationship between a criterion and predictor variable; it does not specify the relationship. The square of the correlation coefficient is a measure of the amount of variance of the criterion variable explained by the predictor variable. McCuen (1993) states that the standard error of estimate is a better measure of goodness of fit than correlation coefficient because the standard error of estimate has the following advantages: it has the same units as the criterion variable, the degrees of freedom are accounted for properly, and it is valid for nonlinear and linear models.

Model coefficient accuracy can be assessed by examining the standard error of the regression coefficient. McCuen (1993) has found from experience that the coefficient is of questionable accuracy if the ratio $S_e(b_i)/b_i$ exceeds 0.3 to 0.4.

The sum of the residuals is examined to determine if there is a bias in the model. If the sum differs from zero, a bias exists. While R^2 is the amount of variation in the criterion variable explained by the predictor variable, the residuals are the variation not explained by the predictor variables.

The principle of least squares assumes a constant error variance. A plot of the residuals versus the independent variable should be obtained to determine if there is any pattern to the residuals. If a pattern exists then the residuals do not have a constant variance.

Respiratory System Background

The main function of the respiratory system is to provide oxygen to the tissues and remove carbon dioxide. This is accomplished through external and internal respiration. External respiration occurs in the lungs whereas internal respiration takes place at the tissue level. External respiration begins as the diaphragm and external intercostal muscles contract, expanding the chest cavity and creating a resultant pressure that is lower than atmospheric (Jensen and Schultz,1970). Due to the lower pressure inside the chest cavity, air rushes into the lungs to equalize pressure. Air is returned to the atmosphere with the subsequent relaxation of the diaphragm and intercostal muscles that increases the pressure within the chest cavity and forces the air out of the body. Thus, at rest, inhalation is considered active whereas exhalation is passive. During exercise, exhalation also becomes active requiring the internal intercostal and abdominal muscles to contract and further reduce the size of the thorax.

The air that is forced into the lungs first enters either through the nose or the mouth and then passes to the pharynx. From the pharynx, the air passes the larynx and enters into the trachea, the start of the tracheobronchial tree. From this point on, the air flow will divide among a set of dichotomously branching tubes in both the left and right lobes of the lung. At each branching, the diameter of the tubes becomes smaller, although the total cross-sectional area increases. From the original branchings off the trachea, the main stem bronchi, through the bronchioles, and into the terminal bronchioles, the air will eventually reach the alveoli. The alveoli are tiny, thin-walled sacs that lie among a bed of capillaries, small diameter blood conduits. It is in the alveoli that gas exchange with the blood occurs. The inspired air carries oxygen to the alveoli and the blood while the expired air carries carbon dioxide from the blood and delivers it to the atmosphere.

The respiratory muscles are controlled by respiratory centers located in the medulla, a part of the autonomic nervous system. As such, breathing is involuntary. An individual may hold his or her breath for a while, but eventually, the person will be forced to take a breath. Factors influencing the control of respiration include: muscular activity, emotions, carbon dioxide concentration, oxygen deficiency, and heart rate (Jensen and Schultz, 1970).

The amount of air that is inhaled or exhaled during each breath is termed the tidal volume. In an average, healthy, resting human, this value is approximately 500 mL (Johnson, 1991). The typical respiration rate of the same typical human is approximately 17 breaths per minute (Johnson, 1991). The minute volume, the amount of air inspired or expired in one minute, is the product of the tidal volume and the respiration rate.

Respiration and Physical Activity

Physical activity begins at some external work rate. This work rate requires a certain amount of internal or physiological work. The increased amount of oxygen required by the body is dependent on the physiological work rate. In response to the increased oxygen consumption, minute volume rises immediately. It then rises at a slower rate to a steady-state value (Johnson, 1991). The increase is exponential with a time constant of 65-75 seconds (Whipp, 1981). More capillaries open in the lung increasing the area for gas diffusion and thus the diffusing capacity of carbon dioxide and oxygen (Berne and Levy, 1988). At a constant moderate rate of exercise below the anaerobic threshold, the minute volume will level off at a steady-state value (Johnson, 1991). Above the anaerobic threshold, a steady state may not be achieved. Tidal volume and respiratory rate also increase. The inhalation and exhalation times shorten.

Wearing a respirator has been shown to affect the pulmonary response to exercise (Johnson et al., 1999). Hypoventilation can occur with a decreased oxygen consumption. The effects of the respirator need to be considered.

External Work

External work is the amount of mechanical work being accomplished. It is equal to the product of force and distance. Work rate, or power, is the work divided by the time to accomplish that work. Work is expressed in units of N·m while work rate is expressed in N·m/s, or Watts (W). So, the external work accomplished by a person with a mass of 70 kg who climbs a set of stairs (total distance: 3 m) is:

$$W_{ext} = (70\text{kg})(9.8\frac{\text{m}}{\text{s}^2})(3\text{m}) = 2058\ \text{N}\cdot\text{m} \qquad (2)$$

The work rate would depend on how fast the person climbed the stairs. If the person took 3 seconds to ascend the stairs then the external work rate would be 686 W. Taking ten minutes to climb the stairs would result in an external work rate of 3.43 W. So, the time to accomplish the task is an important factor in how hard the person is working. Therefore, it is common to use external work rate instead of external work to make comparisons between activities.

Physiological studies often use activities where it is easy to determine the external work rate of a subject. These activities include walking or running on a treadmill, cranking an arm ergometer, pedaling a cycle ergometer, or stepping up and down a block. The work rate when using a bicycle ergometer is (Robergs and Roberts, 1997):

$$WR_{ext} = \frac{cadence \cdot load \cdot \frac{distance}{revolution} \cdot g}{60} \qquad (3)$$

where: WR_{ext}, external work rate, W

cadence, rev/min

load, kg

distance/revolution, m

g is the acceleration due to gravity, m/s^2

60 is a conversion from min to sec

For a Body Guard or Monark ergometer, the distance/revolution is 6 m, while for a Tunturi it is 3 m (Robergs and Roberts, 1997).

The work rate of stepping (W) is:

$$WR_{ext} = h_{step} \cdot mass \cdot n_{step} \cdot g \qquad (4)$$

where: h_{step}, height of the step, m

mass, the mass of the person, kg

n_{step}, number of steps, dimensionless

g, acceleration due to gravity, m/s^2

The work rate of walking is more difficult to assess. In fact, Wasserman et al. (1999) stated that "probably the greatest disadvantage of the treadmill is the difficulty in quantifying the work rate." The external work rate of walking or running on level ground is usually taken to be zero. It's not that work is not being done. Work is done as the body is raised and lowered, but the positive and negative work are usually assumed to offset one another.

Webb et al. (1988) performed a study to determine if the work rate during walking was actually zero. Five male and five female subjects wore a suit calorimeter in a respiration chamber while walking on a level treadmill for 70 to 90 min at speeds of 0.69, 1.28, and 1.86 m/s. The suit calorimeter consisted of a mesh of water-filled tubes that covered the body. The amount of heat transferred to the water in the suit was determined. Subjects also pedaled a bike ergometer for 70 to 90 minutes against loads of 53 and 92 W. For cycling, the energy expenditure calculated from respiratory gas exchange equaled the heat produced plus the external work rate on the bike. However, the heat balance for walking showed that the energy expenditure did not equal the heat produced. This indicated that external work was done in walking. The amount of work done during walking increased with walking speed and was found to be an average of 12% of the transformed energy. The authors concluded that work was done bending the sole of the shoe and in other interactions between the foot and the treadmill surface.

The work of Webb et al. (1988) was continued by Nagle et al. (1990). These investigators had ten male subjects walk on a treadmill while wearing a suit calorimeter. Subjects walked at 1.5 m/s at grades of 10, 5, 0, -5, and 10%. Similar to their previous work (Webb et al., 1988), a non-thermal energy term was found at all grades. So, there is physical work done in grade walking as well as level walking that cannot be accounted for by external work or heat produced. This non-thermal term was significant at grades of 0, 5, and 10% but not at the negative grades. On average, this non-thermal energy term accounted for 6% of the transformed energy, which is half of that reported previously (Webb et al., 1988). While Webb et al. (1988) proposed that the energy was expended in the compression of the heal of the shoe and in bending the sole, the current investigators offered a different explanation. They theorized that a portion of the energy externalized during the positive phase of walking is only partially recovered as heat energy during the negative phase (Nagle et al., 1990).

The external work done in level walking was investigated also by Snellen (1960). Three subjects walked on a level treadmill in a climatic chamber for one hour. The air and wall temperatures were kept close to skin surface temperature so that heat loss through radiation and convection was kept to a minimum. Heat lost through evaporation was calculated. The final heat balance showed that heat gained equaled heat lost. The investigator determined that level walking did not involve external work. It was noted in the article that there were errors in the measurements. Air and wall temperatures did not exactly match weighted skin temperature. Evaporation was determined through weight loss of the subject. Some of the water evaporated comes from the respiratory tract, but the heat of vaporization was determined at average skin temperature.

The different results obtained by Snellen (1960) and Webb et al. (1988) and Nagle et al. (1990) may be due to technique. Webb et al. (1988) and Nagle et al.

(1990) used a suit calorimeter to measure the heat loss by the subject. As the external work rate represented 6% of the energy, it is possible that this non-thermal term was not seen in the study done by Snellen (1960) because of the errors involved in the calculations of heat loss and heat production. In fact, a study conducted by Johnson et al. (2001a) that investigated the heat production in level and grade walking found that there was a difference between the metabolic rate and heat production. While a calorimeter was not used, subjects were thermally insulated from the environment by clothing that consisted of light underwear, a neoprene wet suit, military fatigues, sneakers, sock, two pairs of gloves, a full-facepiece respirator mask, and a neoprene hood. This was done to decrease the heat loss by conduction and evaporation. So, when heat loss and heat gain are monitored carefully, it appears that there is indeed work done in level walking.

A number of approaches have been used to deal with the problem of determining external work during walking. Lakomy (1984) and Cheetham et al. (1986) have used an ergometer system that allows power to be determined during running. Givoni and Goldman (1972), Pandolf et al. (1977), and Aoyagi et al. (1995) provided equations for calculating external work rate. Other authors (Groot et al., 1994) have filmed various activities and determined the work performed.

A treadmill ergometer system was developed by Lakomy (1984). The subject ran on a non-motorized treadmill to which a small generator was attached. The generator gave a voltage proportional to the belt speed. A transducer was mounted at the back of the treadmill. The subject wore a harness around the waist that attached to the transducer. The harness held the subject in place and ensured that the force measured by the transducer was the same as the force applied horizontally on the belt. Instantaneous power was found from the treadmill speed and the force applied to the transducer. Similar types of systems have been used for rowing (Hagerman and Lee, 1971) and swimming (Toussaint et al., 1990).

Equations for external work were presented by Givoni and Goldman (1972) and Aoyagi et al. (1995). The equation provided by Givoni and Goldman (1972) was:

$$\mathrm{WR}_{\mathrm{ext}} = 0.098 \cdot \mathrm{m}_t \cdot \mathrm{v} \cdot \mathrm{G} \tag{5}$$

where: $\mathrm{WR}_{\mathrm{ext}}$, external work rate, W

m_t, total mass, kg

v, velocity, m/s

G, grade, percent

The term 0.098 is the acceleration due to gravity divided by 100. So, equation (5) may be written as:

$$\mathrm{WR}_{\mathrm{ext}} = \mathrm{m}_t \cdot g \cdot \mathrm{v} \cdot \frac{\mathrm{G}}{100} \tag{6}$$

The equation provided by Aoyagi et al. (1995) was:

$$\mathrm{WR}_{\mathrm{ext}} = \frac{3.6 \cdot \mathrm{m}_t \cdot \mathrm{g} \cdot \mathrm{v} \sin\theta}{A_D} \tag{7}$$

where: WR_{ext}, external work rate per area, $kJ/(m^2\,h)$

θ, angle of inclination with respect to the vertical,

(= arctan (G/100)), degrees

If equation (7) is expressed in Watts, it becomes:

$$WR_{ext} = m_t \cdot g \cdot v \sin\theta \tag{8}$$

where: WR_{ext} is the external work rate, W

The difference between equations 6 and 8 is the G/100 and sin θ terms. These terms are equivalent for grades up to 25%.

Other researchers (Groot et al., 1994) filmed subjects during exercise and then determined the individual joint moments and angular velocities. The joint power was found as the product of the joint moments and velocities. The sum of these joint powers reflected the external work rate for the task.

Muscular Efficiency

The amount of power input to a machine is greater than the power output. This is because machines are not 100% efficient. Mechanical efficiency is the power output divided by the power input. Humans are also not 100% efficient. In physiology, mechanical efficiency is referred to as overall or gross efficiency. It is found by dividing the external work rate by the physiological work rate. The physiological work rate, sometimes called the metabolic cost of exercise, is the internal energy required to produce external work.

There are other definitions of efficiency encountered in the literature. There are net efficiency, work or apparent efficiency, delta efficiency, and activity specific efficiencies such as propelling efficiency for swimming. Net efficiency is external work rate divided by the difference of physiological work rate and resting metabolic work rate (Fukunaga et al., 1986). The resting metabolic work rate, or basal metabolic rate, is the amount of energy required by the body for the chemical and metabolic processes required to sustain life. The work or apparent efficiency is found by dividing external work by the difference of physiological work rate and the energy expenditure during non-working conditions. The term work efficiency is used typically for bicycle exercise while apparent efficiency is used for treadmill walking or running (Stainbsy et al., 1980). Delta efficiency is the increment in work rate performed above the previous work rate divided by the increment in physiological work rate above the previous work rate (Fukunaga et al., 1986).

Stainbsy et al. (1980) discussed the validity of base-line subtractions for determining efficiency. The authors indicated that there were differences between exercise efficiency and muscle efficiency. Muscle efficiency should be determined from the processes that provide and convert energy to work (Stainbsy et al., 1980). Exercise efficiency was the external work divided by the energy required to perform that work.

It was suggested (Stainbsy et al., 1980) that muscle efficiency be determined as the product of phosphorylative coupling efficiency and contraction coupling efficiency. The energy for muscular contraction comes from the oxidation of nutrients. Part of this energy is saved in the ATP molecule. This process was termed phosphorylative coupling. The phosphorylative coupling efficiency was found by dividing the free energy conserved as ATP by the free energy of oxidized foodstuff (Stainbsy et al., 1980). Some of the energy from the ATP was used to perform work and was termed contraction coupling. Contraction coupling efficiency was calculated by dividing the external work accomplished by the free energy of ATP hydrolysis (Stainbsy et al., 1980).

The authors argued against using base-line subtractions in determining efficiency because the base line values have been found to change as exercise intensity increases and are thus invalid. They stated that gastrointestinal processes decreased, splanchnic metabolism increased, and energy required by the lungs increased with increasing work rate. Additionally, body temperature increases which then increases the metabolic rate. These factors all caused changes in the base-line values and, according to Stainbsy et al. (1980), precluded the use of efficiencies using base-line subtractions. The authors further stated that while none of the widely used and widely accepted efficiencies (gross, net, apparent, work, and delta) really represent muscle efficiency, there were no errors in using gross efficiency as long as it was referred to as exercise efficiency.

Gross efficiency depends on the work rate, type of work, and which muscles are used. There is a lot of error in the efficiency calculation due to human variability and the fact that external work rate alone does not determine efficiency. Muscular efficiency is influenced by the subject's coordination and familiarity with the activity being performed (Robergs and Roberts, 1997). Wasserman et al. (1999) found that experience in treadmill walking may lead to an increase in efficiency. Activities involving fine movements generally have low efficiencies while activities such as running that involve gross movements and large muscle mass have higher efficiencies (Johnson, 1991). As the resting metabolic demands become a smaller proportion of overall energy requirements, gross efficiency approaches a maximum value of 20% (Johnson, 1991).

Efficiency Studies

Many studies have been performed that investigated the efficiency of various activities. Fukunaga et al. (1986) found that for college oarsmen, the gross efficiency of rowing in the external work rate range of 124 – 182 W was 17.5%. The efficiency of swimming in competitive male and female swimmers ranged from 5 to 9.5% (Toussaint et al., 1990). The authors found that as power output increased, gross efficiency increased also.

Webb et al. (1988) investigated the work done by five males and five females during bicycle ergometer work at 53 and 92 W. Heat production was measured using a suit calorimeter. Gross efficiency for the 53 W and 92 W workloads were 13% and 17%, respectively.

The effects of speed and work rate on muscular efficiency during steady-rate exercise on a bicycle ergometer were investigated (Gaesser and Brooks, 1975). Gross muscular efficiencies were reported at work rates of 33, 65, 98, 131 W at pedaling rates of 40, 60, 80, and 100 rpm. Their results are shown in Table 1. They found that as pedaling frequency increased, efficiency decreased.

Table 1. Gross efficiencies at four work rates and four pedaling rates. Efficiencies are reported as mean ± standard deviation. Data are from Gaesser and Brooks (1975).

	33W	65W	98	131
40 rpm	12.0 ± 0.3%	17.0 ± 0.3%	19.3 ± 0.2%	20.2 ± 0.4%
60rpm	12.1 ± 0.3%	16.6 ± 0.3%	19.2 ± 0.4%	20.4 ± 0.4%
80 rpm	10.2 ± 0.2%	14.8 ± 0.2%	17.6 ± 0.2%	18.8 ± 0.3%
100 rpm	7.6 ± 0.3%	12.1 ± 0.3%	15.1 ± 0.2%	16.6 ± 0.3%

The physiological responses of nineteen subjects to arm, leg, and combined arm and leg ergometry at work rates of 49, 73.5, and 98 W was investigated by Eston and Brodie (1986). Physiological work rate was calculated. The average gross efficiencies for the work rates of 49, 73.5, and 98 W for arm ergometry were 11.8%±0.6%, 12.5%±1.20%, and 12.5%±1.20%. These efficiencies were significantly different from the leg and combined arm and leg efficiencies. For leg ergometry the efficiencies were 13.5%±0.80%, 15.60%±1.40%, 17.11%±1.20% while for the combined arm and leg ergometry the efficiencies were 12.90%±1.30%, 15.20%±1.10%, and 16.8%±1.60%. All efficiencies are reported in order of increasing work rate. There were no statistically significant differences between the leg and combined arm and leg ergometry.

Luhtanen et al. (1987) reported gross efficiencies for subjects on a bicycle ergometer. For work rates of 146±15, 190±4, 225±12, 254±11, and 283±17 W, the gross efficiencies were 19.7%±3.7%, 19.7%±2.8%, 18.9%±2.8%, 18.2%±2.8%, and 17.4±1.0%, respectively. On average, the efficiency of the subjects decreased as external work rate increased.

Nagle et al. (1990) investigated the work done in grade walking on a treadmill. If the non-thermal energy term is ignored (an average of 6% of transformed energy), the efficiencies for walking at a speed of 1.5 m/s at grades of 5, 10, -5, and –10% were 10.6%, 15.8%, -20%, and –48.8% respectively.

Haembraeus et al. (1994) adapted the suit calorimeter used by Webb et al. (1988) and Nagle et al. (1990) so that the suit could be used for exercise intensities of 250W or higher. Unfortunately, external and internal work rates were reported only for two male subjects, one twenty-nine year old and one fifty-five year old. The fifty-five year old subject completed one trial on a bicycle at 100W. The efficiency of the activity was 22%. The twenty-nine year old completed two bike sessions at 200 W and one at 100W. The efficiencies for these activities were 19.4%, 18.9%, and 15.2%.

The muscular efficiency of uphill and downhill walking at a constant speed of 1.1 m/s was investigated by Johnson et al. (2001a). The authors found that the efficiency of downhill walking was negative two times the efficiency of uphill walking. These results were supported by the work of Orsini and Passmore (1951), Pivarnik and Sherman (1990), and Nagle et al. (1990).

Hesser (1965) examined the efficiency of 10 male and 10 females climbing up and down stairs at speeds of 88 steps/min and 160 steps/min. The author found that for the lower speed, the ratio of oxygen cost of positive work to negative work was 8:1. When the speed was increased, the ratio decreased to 5:1. These results contrasted with those of Abbott et al. (1952) and Asmussen (1953) who found that for bicycle ergometer work the ratio increased with speed. The fact that negative work in running or walking is more efficient than positive work is supported by Pimental et al. (1982) and Davies et al. (1974).

Equations Relating Efficiency to External Work Rate

Johnson (1992) developed a series of equations relating gross muscular efficiency to external work rate. Maximum efficiency was assumed to be 20%. The equations were:

$$\eta = \frac{\mathrm{WR}_{\mathrm{ext}}}{200} \qquad 0 \le \mathrm{WR}_{\mathrm{ext}} \le 10 \qquad (9)$$

$$\eta = 0.05 + 0.001(\mathrm{WR}_{\mathrm{ext}} - 10) \qquad 10 \le \mathrm{WR}_{\mathrm{ext}} \le 140 \qquad (10)$$

$$\eta = 0.18 + 0.0002(WR_{ext} - 140) \qquad 140 \le WR_{ext} \le 240 \qquad (11)$$

$$\eta = 0.2 \qquad 240 \le WR_{ext} \qquad (12)$$

where η, muscular efficiency, dimensionless

WR_{ext}, external work rate, W

Physiological Work Rate

Physiological work rate is the internal energy required to produce external work. Physiological work rate is equal to the external work rate divided by the muscular efficiency. For steady-state exercise when there is no change in the body temperature and thus no change in the rate of heat stored, physiological work rate is the sum of the heat produced during exercise and the external work produced.

If the external work is zero, then determining physiological work rate in the above way would give a physiological work rate of zero. If the person is resting, the physiological work rate would equal the basal metabolic rate. However, if the person is running on level ground, the person has a physiological work rate much higher than basal metabolic rate. An alternative to calculating external work rate would be to use a look-up table that provides physiological work rates for walking, running, and other tasks. When a look-up table is used, it is important to consider the conditions under which the values were obtained. Factors such as age, body mass, gender, and fitness level would be important. Tables of physiological work rates for leisure, work, and military tasks can be found in many sources including Johnson (1992), Johnson (1991), and McArdle et al. (1996).

The physiological work rate can also be calculated in another manner. Givoni and Goldman (1971) developed an empirical equation for predicting the metabolic energy cost of level and grade walking, with and without loads. The equation was found to apply to walking speeds of 0.7 m/s to 2.5 m/s at grades up to 25% and for running speeds from 2.22 m/s to 4.72 m/s at grades up to 10% with loads up to 70 kg. The authors suggested empirical coefficients to modify the equation for different terrains, for load placement, and for very heavy work levels. The results showed a correlation of 0.95 between predicted and measured values.

Pandolf et al. (1977) continued the work of Givoni and Goldman (1971) by adjusting the equation to make predictions for subjects who were standing or walking very slowly (less than 0.7 m/s). The authors validated the equation with two studies. The first involved six males walking at speeds of 1.0, 0.8, 0.6, 0.4, and 0.2 m/s while carrying loads of 32, 40, and 50 kg. In the second experiment, ten males stood while wearing backpacks that had masses of 0, 10, 30, and 50 kg. Good agreement was found between the empirical model and the experimental results.

Myles and Saunders (1979) had nine male subjects walk on a treadmill with loads equal to 10% and 40% of body weight. They used the equation developed by Pandolf et al. (1977). Good agreement was found between the predicted and measured values.

Physiological work rate, or metabolic energy cost, can also be determined using either direct or indirect calorimetry. Direct calorimetry measures the amount of heat produced by the body. Indirect calorimetry relates the total metabolic heat production of the body to oxygen consumed and carbon dioxide produced.

With direct calorimetry, the subject is placed typically in a thermally isolated chamber (Ferrannini, 1988) for periods of 24 hours or more. The heat lost through evaporation, radiation, conduction, and convection is measured. These chambers are expensive and are not common. A suit calorimeter was developed that enabled a subject to perform activities outside of a chamber (Webb et al., 1988; Nagle et al., 1990; Hambraeus et al., 1994).

The use of indirect calorimetry began over two hundred years ago when Adair Crawford in England and Antoine Lavoisier in France proved that respiratory gas exchange represented combustion similar to that of a burning candle (Webb, 1991). The energy production results from converting nutrients (carbohydrate, fat and protein) into the chemical energy of ATP minus the energy used in the oxidation process (Ferrannini, 1988). Indirect calorimetry assumes that all of the oxygen consumed is used to oxidize fuel and that all the evolved carbon dioxide is recovered (Ferrannini, 1988). So, measuring oxygen consumed and carbon dioxide produced gives an estimate of the energy production of the body. Swyer (1991) has found that estimations of metabolic energy production made with indirect calorimetry agreed with direct calorimetry values for steady-state conditions if proper procedures were followed.

Many equations have been developed that relate the metabolism of nutrients to the oxygen equivalent of the metabolism. The equations are based on the same theory but differ in their assumptions and intended applications. These equations have been used by many investigators to estimate metabolic energy production.

The theoretical Weir (1949) equation was based on the caloric equivalent of oxygen and carbon dioxide. The equation used total respiratory quotient which includes metabolism of carbohydrate, fat, and protein. Weir assumed that the total percentage of protein calories was between 10 and 14%. If this assumption held, the error in the equation was less than 0.2%. The equation was:

$$\frac{\text{kcal liberated}}{\text{L}\,\text{O}_2\ \text{consumed}} = 3.9 + 1.1\text{RQ} \qquad (13)$$

where: RQ, total respiratory quotient, dimensionless

Garby and Astrup (1987) developed a theoretical equation based on the metabolism of carbohydrate and fat. Protein metabolism was assumed to be zero. Thus, the respiratory quotient used is termed the non-protein respiratory quotient. The equation was:

$$\text{O}_2 - \text{eq.} = \text{A} \cdot \text{NPRQ} + \text{B} \qquad (14)$$

where: O_2 – eq., energy equivalent of oxygen, J/L

A, B, coefficients that depend on the amounts of carbohydrate and fat consumed, J/L

NPRQ, non-protein respiratory quotient, dimensionless

The most commonly used values for the coefficients A and B in equation 14 were 4,940 J/L and 16,040 J/L, respectively (Garby and Astrup, 1987).

A third theoretical equation was presented by Lusk (1928). The equation was:

$$\frac{cal}{LO_2\ consumed} = 4.686 + \frac{0.361 \cdot (RER - 0.707)}{0.293} \tag{15}$$

where: RER, respiratory exchange ratio, dimensionless

The Weir (1949), Garby and Astrup (1987), and Lusk (1928) equations all determined the energy equivalent of oxygen. Physiological work rate was determined from these equations by multiplying the energy equivalent of oxygen by the oxygen consumption and converting units. The equations for predicting physiological work rate from the Weir, Garby and Astrup, and Lusk equations, respectively were:

$$\mathrm{WR}_{\mathrm{phys}} = \frac{(4606\mathrm{RQ} + 16329)V_{O2}}{60} \tag{16}$$

$$\mathrm{WR}_{\mathrm{phys}} = \frac{(4940\mathrm{NPRQ} + 16040)V_{O2}}{60} \tag{17}$$

$$\mathrm{WR}_{\mathrm{phys}} = \frac{(5155\mathrm{RER} + 15962)V_{O2}}{60} \tag{18}$$

where: $\mathrm{WR}_{\mathrm{phys}}$, physiological work rate, W

V_{O2}, oxygen consumption, L/min

Gagge and Nishi (1983) presented an equation for predicting metabolic energy from oxygen consumption and carbon dioxide production:

$$WR_{phys} = (0.23RER + 0.77)(5.873)V_{O2}(60) \tag{19}$$

where: WR_{phys}, physiological work rate, W

RER, respiratory exchange ratio, dimensionless

V_{O2}, oxygen consumption, L/min

5.873, energy equivalent of oxygen, W·hr/L

The authors recommended that the equation not be used for transient conditions. Putting their equation in the same format as above yielded:

$$WR_{phys} = \frac{(4863RER + 16280)V_{O2}}{60} \tag{20}$$

where: WR_{phys}, physiological work rate, W

RER, respiratory exchange ratio, dimensionless

V_{O2}, oxygen consumption, L/min

The four equations (16 – 18, 20) have similar coefficients. Some of the equations used respiratory quotient while others used respiratory exchange ratio.

The respiratory quotient is defined as the ratio of the rate of carbon dioxide produced to the rate of oxygen consumed. The respiratory exchange ratio is defined as the ratio of the rate of carbon dioxide exhaled to the rate of oxygen consumed. So, the difference is in the carbon dioxide term. RQ deals with cellular respiration and is used to calculate the caloric value of oxygen consumption. RER is related to external respiration and is an indication of the work intensity. RQ and RER can be considered to be equal except under the following conditions: metabolic acidosis, non-steady state conditions, hyperventilation, excess post-exercise oxygen consumption, and extremely heavy exercise (Robergs and Roberts, 1997; Johnson, 1991).

The RQ cannot exceed 1.0 because the carbon dioxide produced by cells cannot exceed the oxygen consumed. However, when excess acid is produced (metabolic acidosis) such as during heavy exercise, the body produces increased levels of carbon dioxide separate from oxygen consumption due to buffering of the carbon dioxide. Because of the excess carbon dioxide produced, RER can exceed 1.0 under conditions of metabolic acidosis.

Under non-steady state conditions, oxygen consumption has not had a chance to increase to levels that account for ATP produced during metabolism. Instead, the ATP comes from creatine phosphate hydrolysis and glycolysis. So, a lower metabolic intensity would be indicated during the transition than if the person had already achieved a steady state (Robergs and Roberts, 1997).

During hyperventilation, the volume of carbon dioxide exhaled from the lung increases. This can occur without increases in oxygen consumption, so the RER may be increased. The RQ would remain the same because the carbon dioxide produced by the cells had not increased.

Finally, after exercise, the amount of carbon dioxide exhaled decreases rapidly while the oxygen consumption remains elevated above resting levels. Thus, the RER may decrease below resting values (Robergs and Roberts, 1997).

The actual physiological work rate can be less than the predicted when there are connections between a subject and the test apparatus other than, for example, the connection between the shoes and the treadmill belt. Wasserman et al. (1999) stated that railings, armboards, mouthpieces, blood pressure measuring devices, and steadying hands could all reduce the patient's metabolic requirement. The mass of shoes and stiffness of their soles may affect the physiological work rate (McArdle et al., 1996). Loads carried on the foot increase the physiological work rate more than loads carried on the torso. So, heavy shoes would cause a greater increase in physiological work rate than lightweight shoes. Softer-soled shoes reduce the physiological work rate compared to stiffer soled shoes.

Oxygen Consumption

As long as the work rate is not too high during constant-rate exercise, oxygen consumption will reach a steady-state. A secondary rise in oxygen consumption, or oxygen drift, may occur for extended periods of exercise (Poole and Richardson, 1997; Kearon et al., 1991). There appears to be both a fast and slow component to oxygen consumption during work. The fast component is responsible for the initial steady-state reached. The oxygen drift is thought to be related to the slow component. The slow component may also cause a greater than linear increase in the oxygen consumption with work rate above the anaerobic threshold. The presence of oxygen drift would be important to consider for a model of steady-state exercise.

There are exercise levels for which oxygen consumption will continue to rise until the maximum oxygen consumption is reached, fatigue occurs, and exercises stops. While it may not be possible physiologically for a subject to attain the steady-state, the theoretical steady-state value is still necessary to determine the response (Givoni and Goldman, 1972).

Slow Component of Oxygen Consumption

Poole and Richardson (1997) stated that the four most important determinants of oxygen consumption response during exercise were external work rate, work efficiency, whether the work was incremental or constant load, and the intensity level of the work (above or below the anaerobic threshold). The heavy exercise domain starts at the anaerobic threshold. The highest exercise level in this domain is the highest work rate at which blood lactate production can be stabilized, albeit at an elevated level (Poole and Richardson, 1997). The slow component of oxygen consumption is evident in this domain 80-100 seconds after the start of exercise (Poole and Richardson, 1997). Work efficiency is reduced in this domain.

The severe exercise intensity domain begins around 50% of the difference between the anaerobic threshold and V_{O2max} (Poole and Richardson, 1997). In this domain, blood lactate levels continue to increase and the slow component pushes the oxygen consumption towards V_{O2max}.

Gaesser and Poole (1996) suggested that the increase in oxygen consumption for exercise above the anaerobic threshold (slow component) not be confused with oxygen drift. The authors suggested that oxygen drift occurs during prolonged moderate intensity exercise and is a small increase (200mL) in the oxygen consumption. The slow component of the oxygen consumption response on the other hand is only seen for exercise above the anaerobic threshold and is of much greater magnitude. It is the increase in oxygen consumption beyond the third minute of exercise (Gaesser and Poole, 1996).

Whipp and Wasserman (1972) investigated the oxygen uptake kinetics for various intensities of constant-load work. They found that for low work rates, the oxygen consumption reached a steady-state within three minutes. At higher work rates, the steady-state was progressively delayed. A difference was found between the oxygen consumption measured at three minutes and that measured at six minutes. The authors found that this difference was a useful indicator of the slow component of oxygen consumption.

Kearon et al. (1991) investigated oxygen consumption, minute ventilation, tidal volume, and respiratory rate during prolonged exercise at work rates of 34%, 43%, 63%, and 84% of maximal capacity in six healthy subjects. Subjects exercised for 60 minutes or until they could not continue. The average (± standard error of the mean) performance times at the four work rates were 60 ± 0 min, 56 ± 4.0 min, 37 ± 6.6 min, and 12 ± 3.7 min, respectively. A regression line was fit to the average oxygen consumption data versus time for each of the work conditions. Data collected in the first four to six minutes was ignored as this was considered to be the time it took for the subjects to reach a steady state. A statistically significant increase in the oxygen consumption was declared if the slope of the regression line was significantly different from zero.

At the lowest work rate, there was a small but statistically significant increase in the oxygen consumption from 1.47 to 1.52 L/min. Oxygen consumption increased during the 43% work rate from 1.76 to 1.93 L/min. the differences at these two work rates were in the 200 mL range that Gaesser and Poole (1996) suggested indicates oxygen drift rather than the slow component. For the third work rate, oxygen consumption increased from 2.35 L/min to 2.84 L/min. Finally, oxygen consumption values for the highest work rate increased from 3.13 to 3.59 L/min. All of the increases were statistically significant.

Barstow and Mole (1991) investigated oxygen uptake kinetics during heavy exercise. Four trained cyclists completed four replications of cycle exercise at four work rates, two of which were below the anaerobic threshold. The four work rates were 35, 55, 85, and 100% of maximal oxygen consumption. Each test consisted of four minutes of pedaling at 33W followed by eight minutes at the selected work rate and then ten minutes of recovery at 33W. Two exponential models were fit to the data:

$$\Delta \dot{V}_{O_2}(t) = A_1\left[1 - e^{-(t-TD)/\tau_1}\right] + A_2\left[1 - e^{-(t-TD)/\tau_2}\right] \qquad (21)$$

$$\Delta \dot{V}_{O_2}(t) = A_1\left[1 - e^{-(t-TD_1)/\tau_1}\right] + A_2\left[1 - e^{-(t-TD_2)/\tau_2}\right] \qquad (22)$$

where: $\Delta V_{O2}(t)$, oxygen consumption response above baseline, L/min

t, time starting from the onset of exercise, sec

A_1, first steady-state oxygen consumption, L/min

A_2, second steady-state oxygen consumption, L/min

TD_1, TD_2, time delays for phase two and three, respectively, sec

τ_1, τ_2, time constants for phase two and three, respectively, sec

The difference between the two equations was that the second equation was a more general form that allowed a second independent time delay.

A single-exponential function of the form:

$$\Delta \dot{V}_{O_2}(t) = A_3\left[1 - e^{-(t-TD)/\tau_3}\right] \qquad (23)$$

where: A_3, the sum of A_1 and A_2 from the first equation

τ_3 equals τ_1 and τ_2

fit the data for all eight exercise cases below the anaerobic threshold (two work rates for each of four subjects). So, for the oxygen consumption response below the anaerobic threshold, there is only one steady-state value, A_3.

For seven of the eight responses above the anaerobic threshold, a two-exponential function (equation 22) was found to fit the data. For the eighth case, the single exponential function (equation 23) was the best fit. The better fit of the two-exponential model indicated that for exercise above the anaerobic threshold there was a second component to the oxygen consumption that did not begin at the same time as the first exponential, but began later into the exercise. The authors concluded that this was evidence of a slow component of the oxygen consumption response. Equation 22 was modified in a later study (Mole and Hoffmann, 1999) to include baseline oxygen consumption in the response:

$$\Delta \dot{V}_{O_2}(t) = \alpha_R + \alpha_F\left[1 - e^{-(t-TD)/\tau_F}\right] + \alpha_S\left[1 - e^{-(t-TD)/\tau_S}\right] \qquad (24)$$

where: α_R, initial resting oxygen consumption, L/min

α_F, steady-state V_{O2} due to the fast component, L/min

α_S, steady-state V_{O2} due to the slow component, L/min

τ_F, time constant for the fast component, sec

τ_S, time constant for the slow component, sec

Similar results were found by Paterson and Whipp (1991). Six healthy subjects performed two to four repetitions of cycle exercise from a baseline of unloaded pedaling to one of two selected work rates, one at 90% of the anaerobic threshold and the other at the halfway point between the anaerobic threshold and V_{O2max}. A single-exponential function was the best fit equation for the oxygen consumption response for the exercise below the anaerobic threshold. For exercise above the anaerobic threshold, the authors found that a two-exponential model, with separate time constants and time delays was the most accurate model. It was concluded that the slow component of the oxygen consumption response was a delayed-onset process. The two-exponential model has been shown to be accurate for predicting the steady-state oxygen consumption for exercise intensities above the anaerobic threshold (Bernard, et al., 1998). The two exponential response of oxygen consumption with time has been shown also in untrained subjects (Camus, et al., 1988).

The physiological reason or reasons for the slow component of oxygen consumption are still under debate. Possible reasons include lactate, epinephrine, cardiac and ventilatory work, temperature, potassium, and recruitment of lower-efficiency fast-twitch muscle fibers (Gaesser and Poole, 1996). Poole et al. (1992) showed that most (86%) of the increase in oxygen consumption beyond the third minute was due to a increase in leg oxygen consumption. So, Gaesser and Poole (1996) suggested that factors that do not involve working muscles probably make only small contributions to the slow component. They suggested that muscle temperature and more importantly, the recruitment of lower efficiency fast-twitch muscle fibers were the major factors contributing to the slow component.

Steady-State Oxygen Consumption

Equations that related physiological work rate to RQ, NPRQ, or RER and oxygen consumption have been discussed previously. If the physiological work rate were calculated using a separate method, the above equations could be solved for oxygen consumption in terms of physiological work rate and RQ, NPRQ, or RER.

Johnson (1992) fit equations to experimental data in Hurley et al. (1984) that related respiratory exchange ratio to percent of maximum oxygen consumption for trained and untrained subjects:

$$RER = 0.842 \qquad 0 \le \frac{V_{O2}}{V_{O2\max}} \le 0.1 \qquad \text{untrained} \tag{25}$$

$$RER = 0.778 \qquad 0 \le \frac{V_{O2}}{V_{O2\max}} \le 0.1 \qquad \text{trained} \tag{26}$$

$$RER = 0.826 + 0.160\left(\frac{V_{O2}}{V_{O2\max}}\right) \qquad 0.1 \le \frac{V_{O2}}{V_{O2\max}} \le 0.8 \qquad \text{untrained} \tag{27}$$

$$RER = 0.756 + 0.220\left(\frac{V_{O2}}{V_{O2\max}}\right) \qquad 0.1 \le \frac{V_{O2}}{V_{O2\max}} \le 0.9 \qquad \text{trained} \tag{28}$$

$$RER = -0.230 + 1.480\left(\frac{V_{O2}}{V_{O2\max}}\right) \qquad 0.8 < \frac{V_{O2}}{V_{O2\max}} \qquad \text{untrained} \tag{29}$$

$$RER = -0.810 + 1.960\left(\frac{V_{O2}}{V_{O2\max}}\right) \qquad 0.9 \le \frac{V_{O2}}{V_{O2\max}} \qquad \text{trained} \tag{30}$$

where: RER, respiratory exchange ratio, dimensionless

V_{O2}, oxygen consumption, L/min

V_{O2max}, maximum oxygen consumption, L/min

These equations assumed RER=1.25 for untrained and RER=1.15 for trained individuals.

Johnson's (1992) RER equations could be substituted for NPRQ in the physiological work rate equation that could then be solved for oxygen consumption. For very heavy exercise, errors in calculating the oxygen consumption and subsequent parameters would result when substituting RQ for RER. These errors should be evaluated.

Other methods of determining oxygen consumption from work have been developed. Astrand and Rodahl (1970) showed in their Figure 13-2 that oxygen consumption was related linearly to physiological work rate. ACSM (2000) provided equations for estimating oxygen consumption for treadmill walking or running, ergometry, and stepping. Van der Walt and Wyndham (1973) developed equations to predict oxygen consumption for level treadmill walking and running. Their equations were of the form:

$$\dot{V}_{O_2} = A_1 + A_2 m + A_3 m v^2 \qquad (31)$$

where: A_1, A_2, and A_3, empirically derived regression coefficients

m, mass, kg

v, velocity, m/s

The authors did not investigate the effects of loads carried, grade, or of ambulating on surfaces other than a treadmill. Equations such as those developed by ACSM (2000) and Van der Walt and Wyndham (1973) are useful for predicting oxygen consumption of specific activities, but have no use in predicting the oxygen consumption of other activities such as painting or wood working. The Astrand and Rodahl (1970) plot may show an idealized relationship, but is worth considering.

Astrand and Rodahl (1970) showed that the absolute oxygen consumption required by the body depended on the physiological work rate (their Figure 13-2). Logically, the higher the work rate, the greater the amount of oxygen consumed. Because their graph showed a completely straight line with no regression equation, the graph may show an idealized relationship.

Effects of Age and Training

The following factors may cause the actual oxygen consumption to differ from the predicted: faulty ergometer calculation, obesity, cardiovascular disease, pulmonary disease, fitness, exercise protocol, handrail holding, stride length, training specificity, habituation, and coordination (Robergs and Roberts, 1997; Wasserman et al., 1999). For trained individuals, steady-state oxygen consumption is lower at a given work rate than for untrained individuals due to an attenuation of the slow component (Gaesser and Poole, 1996). The reason for the decrease in the V_{O2} slow component may be due to the increase in mitochondria in all fibers that occurs with endurance training. Training also can speed up the transient response while detraining and cardiopulmonary disease can decrease the response (Poole and Richardson, 1997). Children have a greater gain for the fast component than adults and exhibit little or no slow component (Barstow, 1994).

Anaerobic Threshold

The point at which the lactate levels in the blood begin to rise during incremental exercise has been termed the anaerobic threshold (AT) (Wasserman, 1973). When the oxygen required by the muscles can be supplied by ventilation alone, metabolism occurs aerobically. If the oxygen demand of the exercising muscles cannot be supplied by ventilation alone, then ATP production does not occur at the mitochondrial level (Claiborne, 1984) but is instead produced anaerobically (Sady, et al., 1980). Thus, around the anaerobic threshold, non-oxidative metabolism plays more of a role in energy production (Sady et al., 1980). Lactic acid production increases and is buffered by the bicarbonate system (Weltman and Katch, 1979), resulting in an increase in the production of non-metabolic carbon dioxide. The increase in CO_2 production acts as an strong ventilatory stimulus (Sady et al., 1980), causing the minute ventilation-oxygen consumption relationship to increase beyond linear (Wasserman, 1973).

There are invasive and non-invasive techniques for determining the anaerobic threshold. Wasserman et al. (1973) stated that the AT was the point of: "1) nonlinear increase in minute ventilation, 2) nonlinear increase in carbon dioxide production, 3) an increase in end-tidal oxygen without a corresponding decrease in end-tidal carbon dioxide, and 4) and increase in the respiratory exchange ratio, as work rate was increased during exercise." The term "lactate threshold" is sometimes used to describe the point at which lactic acid begins to accumulate in the blood (Johnson, 1991; Johnson et al., 1995). The point at which minute ventilation increases beyond linear is sometimes called the "ventilation threshold" (Johnson, et al., 1995; Mahon and Vaccaro, 1989).

Other researchers disagreed with the description of anaerobic threshold provided in Wasserman et al. (1973). Skinner and McLellan (1980) labeled the set of responses observed by Wasserman et al. (1973) as the "aerobic threshold". They contended that there were really three phases to exercise, not two. The second breakaway point was described as the point at which lactic acid increased from 4 mmol/L, FE_{CO2} decreased, and hyperventilation increased. This point occurred between 65-90% of V_{O2max} and was termed the "anaerobic threshold" (Skinner and McLellan, 1980).

There has been some disagreement about whether the AT as determined by blood analysis is the same as that determined from respiratory gas exchange. Powers et al (1984) compared the onset of AT measured by blood lactate and estimated by the point where ventilation increased non-linearly. They found that the two points did not always occur simultaneously and suggested that there may be limitations to estimating the AT using respiratory gas exchange. However, Ivy et al. (1980) found that there were no significant differences between the two methods of estimating the AT. Davis et al. (1976) found a correlation coefficient of 0.95 between the two methods.

One of the major problems with determining AT using respiratory gas exchange is the subjectivity involved (Davis et al., 1976). Computer programs that use objective methods of determining AT from respiratory gas exchange have been developed (Herbert et al., 1982; Orr, et al., 1980). This eliminates the problem resulting from researcher subjectivity in detecting the point at which the curve departs from linearity.

A new method of detecting the AT from gas exchange variables was presented by Caprarola and Dotson (1985). They plotted FE_{CO2} versus percent of maximal oxygen consumption and fit a quadratic equation to the data. The point at which the curve was a maximum was the anaerobic threshold. The authors found good agreement between this method and standard techniques.

Johnson et al. (1995) investigated the effects of full-facepiece masks and half-masks on ventilation threshold and lactate threshold on fourteen subjects undergoing incremental bicycle exercise. These researchers found that mask condition did not affect either the lactate or ventilation thresholds.

Many studies investigating the relationship between anaerobic threshold and oxygen consumption have been performed. Subjects of these studies have been male and female, trained and untrained.

Weltman et al. (1978) reported that for thirty-three female college students, the AT occurred at an average of 50% of V_{O2max}. These researchers paired 22 subjects according to their V_{O2max} values. Paired members had similar V_{O2max} values but different AT values. The average V_{O2max} for the two groups (36.66± 7.62 and 38.36±6.28 for the low and high AT groups respectively) were not significantly different statistically. The AT values were significantly different. The AT values for the low and high AT groups were 16.23 ±4.57 L/min and 21.35±4.14 L/min, respectively. This corresponded to an AT% of 44% and 56% for the low and high AT groups respectively. So, even though the two groups had similar subjects, the AT (ml/kg/min) was quite different.

Dwyer and Bybee (1983) reported that the AT occurred at an average of 70±7% of V_{O2max} for twenty female recreational runners and cyclists. Average V_{O2max} was 38.4±4.7 ml/kg/min. They found a high correlation ($r = 0.87$) between AT (L/min) and V_{O2max} (L/min).

Fifteen trained female cross-country skiers aged fifteen to twenty with an average V_{O2max} of 47.3±3.6 ml/kg/min were studied (Rusko et al., 1980). The AT (40.9±3.3 ml/kg/min) occurred at 85.7±6.6% of V_{O2max}. A correlation ($r=0.6$) was found between V_{O2max} (ml/kg/min) and AT (ml/kg/min). An insignificant correlation was found between AT expressed as a percent of V_{O2max} (AT%) and V_{O2max} (ml/kg/min).

Eighteen overweight females were studied by Sady et al. (1980). Subjects were split into three groups for different exercise treatments. Pre-training V_{O2max} and

AT values are reported for each of these three groups separately. The V_{O2max} values for the three groups (n=7, n=7, and n=4) were 2.23±0.07, 2.09±0.18, and 2.31±0.12 L/min while the AT values were 1.02±0.06, 0.97±0.04, and 1.28±0.08 L/min, respectively. These AT values corresponded to 46, 46, and 55% of VO2max, respectively.

Thorland et al. (1980) studied ten trained female collegiate cross-country runners. The AT occurred at average of 80% of V_{O2max}. The anaerobic threshold expressed in ml/kg/min was highly correlated with maximal oxygen consumption (r = 0.81).

Weltman and Katch (1979) found that thirty-one male subjects with an average V_{O2max} of 51.36±6.36 ml/kg/min had an AT of 59.5±7.70% of V_{O2max}. They found a high correlation (r=0.81) between V_{O2max} (L/min) and AT (L/min).

Thirteen trained men were studied by Powers et al. (1984). The AT of these subjects occurred at an average of 56% of V_{O2max}. Balsom (1988) studied fourteen male college soccer players with an average V_{O2max} of 57.4±6.18 ml/kg/min. The average AT occurred at 70.5±5.99% of V_{O2max}. Robbins et al. (1982) found that for healthy adult males with a mean V_{O2max} of 59.2 ml/kg/min, the AT occurred at an average of 65.3% of VO2max. For male college students performing arm-cranking, leg cycling, and treadmill walk-running, the AT occurred at average values of 46.5, 63.8, and 58.6% of VO2max, respectively (Davis et al., 1976). Jones (1984) found that the AT occurred at 50% ± 4.8% of the V_{O2max} for inactive, young, adult male smokers (average V_{O2max}: 34 ml/kg/min). For males aged 24-35, Bradley (1982) found that AT occurred at 58.6%±10.7% of V_{O2max} (average V_{O2max} was 45.7 ± 7.9 ml/kg/min).

These studies show that the occurrence of the AT is highly variable even among subjects of the same gender and similar ages and training statuses. Skinner and McLellan (1980) reported that the anaerobic threshold occurs between 65 and 90% of V_{O2max}. The studies discussed here have shown values outside this range. These studies have reported that the anaerobic threshold can occur between 29 and 95% of maximal oxygen consumption. The anaerobic threshold for trained athletes occurs at a higher percentage of V_{O2max} than for untrained subjects. While the AT can be elevated after training even if there is not an increase in V_{O2max} (Claiborne, 1984), generally the higher the V_{O2max}, the higher the AT.

A significant relationship between the AT and V_{O2max} was reported by Dwyer and Bybee (1983), Rusko et al. (1980), Thorland et al. (1980), and Weltman and Katch (1979). The other researchers did not report on this relationship. Only one paper reported regression of AT% on V_{O2max} (Rusko et al., 1980); no correlation was found.

The anaerobic threshold is important because relationships below the anaerobic threshold differ from the relationships above the anaerobic threshold (Johnson, 1991). Martin and Weil (1979) found that for incremental exercise below the anaerobic threshold, the minute volume increased linearly while above the threshold it increased at a greater rate. And, the time to reach a steady-state in oxygen consumption is longer above the anaerobic threshold (Wasserman et al., 1973).

Wasserman et al. (1973) suggested that for patients with severe respiratory impairment, an AT may not be present because these subjects might not be able to exercise at a high enough rate to elicit lactic acidosis. For subjects with cardiovascular impairment, the anaerobic threshold will occur at lower values than for healthy subjects (Wasserman, et al., 1973).

Minute Ventilation

Minute ventilation is the amount of air exhaled in one minute. It is found as the product of respiration rate and tidal volume. At rest, the minute ventilation is around 5-6 L/min. During mild exercise, this can increase to 75 L/min while during maximal exercise values up to 160 L/min occur. For endurance athletes, the minute ventilation may increase to as much as 27 times the resting value (Robergs and Roberts, 1997). As long as exercise intensity is not too high, the minute ventilation will reach a steady state. Because minute ventilation is related to oxygen consumption, an increase in the oxygen consumption due to oxygen drift or the slow component would cause a concomitant increase in the minute ventilation. During exercise with a progressive work rate, below the anaerobic threshold, minute volume increases linearly with oxygen consumption. Above the anaerobic threshold, minute volume increases exponentially (Martin and Weil, 1979).

For constant rate work below the anaerobic threshold, minute ventilation reaches a steady-state (Wasserman et al., 1980). For exercise above the anaerobic threshold, the time to reach steady state is prolonged. For very heavy exercise, a steady state may not be reached before the subject has to cease exercise.

When constant rate work below the anaerobic work begins from rest, there is an initial abrupt rise in minute ventilation (Whipp et al., 1982; Johnson, 1991). The abrupt rise is thought to be neurogenic in nature (Johnson, 1991; McArdle et al., 1996). There may be a short duration plateau (20 seconds) immediately after the abrupt rise. Minute ventilation then increases exponentially to a steady state if the exercise is not too intense (McArdle et al., 1996). The steady state value attained depends on the intensity of exercise. If the work rate is very high, a steady state will not be achieved and the minute ventilation will increase progressively until the person ceases exercise (Wasserman et al., 1980).

There is a large variability in the response of minute ventilation, and other respiratory parameters, to exercise. In fact, Johnson (1991) states that "respiratory responses are difficult to reproduce" and recommends that applications to individuals be made with caution. The variability of the minute ventilation response is less when related to carbon dioxide production instead of oxygen consumption (Wasserman et al., 1980). This indicated the importance of carbon dioxide in the control of respiration (Johnson, 1991).

At low levels of exercise, increases in minute ventilation are brought about mainly by an increase in tidal volume, while at higher intensity levels, minute ventilation increases as a result of increased respiration rate (Johnson, 1991; McArdle et al., 1996).

Factors That Affect Minute Ventilation

Age, training, and gender affect minute ventilation. Maximal minute ventilation decreases with age. Additionally, for a given submaximal oxygen consumption (e.g., 2 Lpm), older subjects will have a higher minute ventilation than younger subjects (Robergs and Roberts, 1997). Training results in a higher maximal minute ventilation during maximal exercise. During submaximal exercise, there is a reduction in the minute ventilation at a particular oxygen uptake after training. This indicates a lower oxygen cost of exercise for breathing (McArdle et al., 1996). Because minute ventilation is related to body mass, male subjects generally have higher minute ventilations than female subjects (Johnson, 1991).

Tidal Volume

Tidal volume is the amount of air exhaled with each breath. While some authors (McArdle et al., 1996; Robergs and Roberts, 1997) define tidal volume as the volume of air either inhaled or exhaled, these two volumes are not the same. The difference results mainly from the different temperatures of the inhaled and exhaled air. The different water vapor addition and different gas composition are smaller factors (Johnson, 1991).

Tidal volume varies with age, gender, and size (McArdle et al., 1996). Males generally have larger tidal volumes than females. An average resting tidal volume for men is 600 mL while that for a woman is 500 mL. During exercise, tidal volume can reach values of 2 – 3 L. Tidal volume can be quite variable even when the subject is at steady state (Johnson, 1991). The interbreath variation is caused predominantly through changes in the inspiratory time.

During exercise, tidal volume is increased by using parts of the inspiratory and expiratory reserve volumes. These volumes are the amount of air present in the lungs after a normal inhalation or exhalation. At low intensity exercise, the tidal volume increases causing an increase in the minute ventilation. Once the tidal volume reaches 50 – 60% of the vital capacity, the minute ventilation is further increased through an increase in the respiratory rate (Wasserman et al., 1999). Vital capacity is the sum of the inspiratory reserve volume, expiratory reserve volume, and tidal volume. Maximum tidal volume has been reported to range from 45 – 58% of vital capacity (Wasserman et al., 1999).

For constant rate exercise below the anaerobic threshold, the tidal volume is relatively constant with time. For exercise above the anaerobic threshold, the tidal volume may decrease slightly with time (Wasserman et al., 1980).

Exhalation and Inhalation Times

The prediction of inhalation and exhalation times can be accomplished using different approaches. Caretti et al. (1992) investigated the effects of exercise modality on breathing patterns. Subjects exercised on a bicycle ergometer and a treadmill. Other investigators have average consecutive breaths with different breathing frequencies and then evaluated the inhalation and exhalation times. Caretti et al. (1992) examined individual breathing frequencies and inhalation and exhalation times. Their rationale was that when consecutive breaths were averaged, the variability in breathing patterns and timing differences related to breathing frequency was masked. Individual breathing frequencies were grouped together into bins to aid in the analysis.

The authors plotted inhalation and exhalation time versus breathing frequency. A regression curve was not fitted to the data, but a the relationship was observed to be similar to a power-law relationship. This relationship was qualitatively similar for both treadmill and bike exercise except for respiration rates below 12 breaths/min. Below 12 breaths/min, the investigators found that exhalation time was significantly longer for treadmill exercise compared to bike exercise. A large variability in inhalation and exhalation times was observed for breathing frequencies below 18 breaths/min. Above 18 breaths/min, the variability decreased.

So, Caretti and Whitley (1998) showed that inhalation and exhalation times could be predicted from respiratory rate. Johnson and Masaitis (1976) took a different approach.

By minimizing total respiratory work during a complete respiratory cycle, Johnson and Masaitis (1976) derived an equation to predict the ratio of inhalation time to exhalation time:

$$\tau^3 - \left(\frac{\lambda}{1+\mu}\right)\tau - \left(\frac{\mu\eta}{1+\mu}\right) = 0 \qquad (32)$$

where:

a) $\tau = \left(\frac{t_i}{t_e}\right)$ (33)

where τ = inhalation time/exhalation time ratio, dimensionless

t_i = inhalation time, seconds

t_e = exhalation time, seconds

b) $\lambda = \left(\frac{K_{1i}}{K_{1e}}\right)$ (34)

where λ = ratio of first inhalation and exhalation Rohrer coefficients, dimensionless

K_{1i} = first Rohrer coefficient for inhalation, (cm $H_2O \cdot sec$)/L

K_{1e} = first Rohrer coefficient for exhalation, (cm $H_2O\cdot$sec)/L

c) $$\eta = \left(\frac{K_{2i}}{K_{2e}} \right) \tag{35}$$

where η = ratio of first inhalation and exhalation Rohrer coefficients, dimensionless

K_{2i} = second Rohrer coefficient for inhalation, (cm $H_2O\cdot$sec)/L

K_{2e} = second Rohrer coefficient for exhalation, (cm $H_2O\cdot$sec)/L

d) $$\mu = \left(\frac{2K_{2e}V_T}{K_{1e}t_e} \right) \tag{36}$$

where μ = dimensionless ratio

V_T = tidal volume, L

The Johnson and Masaitis (1976) model assumes: "1) inhalation/exhalation times are determined by respiratory work during one cycle; 2) expiratory work is important in determining inhalation/exhalation times; 3) energy stored during inhalation due to respiratory system compliance or inertance is fully recovered during exhalation." Equation 32 is a cubic equation and can be solved using a method such as Cardan's solution (Korn and Korn, 1961). Inhalation and exhalation times were determined using an iterative process. The authors showed that the model had good qualitative and quantitative agreement between calculated and experimental results.

Effect of Inspiratory and Expiratory Loading

Resistance loading of the respiratory system causes changes in the respiration rate and in the duration of inhalation and exhalation. Inspiratory loading leads to an increased inhalation time and a decreased respiration rate. The subsequent exhalation is affected as well, with an increased exhalation time following an increased inhalation time (Cherniack and Altose, 1981). Expiratory loading leads to increased exhalation times and decreased respiration rates. These effects were shown by Caretti and Whitley (1998), Johnson et al. (1999) and Caretti et al. (2001).

The effect of inspiratory resistance breathing on respiratory rate was investigated by Caretti and Whitley (1998). Subjects exercised on a treadmill at 80-85% of V_{O2max} while wearing a half-respirator with one of four inspiratory resistances ranging from 0.2 kPA to 0.49 kPa, measured at a steady airflow rate of 1.42 m/s. Treadmill speed and grade were adjusted for each resistance condition so that the subject was at 80-85% of V_{O2max}. Respiratory rate decreased from the control condition 4.6%, 10.7%, 16%, and 32% for the four resistance conditions. The respiratory rate for R4 (highest resistance) was significantly different from the control, R1, and R2 conditions.

Johnson et al. (1999) investigated the effects of inspiratory resistance on work performance. Subjects exercised on a treadmill at constant speeds and grades that were chosen to elicit respiratory stress. A full-facepiece respirator was worn for each of six tests with different levels of inspiratory resistance. The inhalation resistances ranged from 0.78 to 7.64 cm $H_2O\cdot$sec/L. The exhalation resistance for all tests was

1.3 cm $H_2O \cdot sec/L$. It was found that minute volume decreased as inhalation resistance increased:

$$\dot{V}_{min} = -.0687R + 1.325 \tag{37}$$

where: $\dot{V}_{min}$, minute volume, L/sec

R, resistance, cm $H_2O \cdot sec/L$

Caretti et al. (2001) conducted a similar study investigating the effects of exhalation resistance on work performance. Exhalation resistances ranged from 0.27 to 27.35 cm $H_2O \cdot sec/L$. Average minute volumes decreased as expiratory resistance increased:

$$\dot{V}_{min} = -1.76R + 73.16 \tag{38}$$

So, in both cases (Johnson et al., 1999; Caretti et al., 2001), as resistance increased, minute volume decreased. Caretti and Whitley (1998) found that tidal volume did not change with resistance for exercise at 80-85% of V_{O2max}. So, assuming a constant tidal volume during steady state work, a decrease in the minute volume would lead to a decreased respiratory rate.

Oxygen Deficit

Because the oxygen consumption does not rise immediately to the steady state value, there is a difference between the oxygen required by the body (the steady state value) and the actual oxygen consumption (that during the exponential increase). This difference is termed the oxygen deficit. The oxygen deficit is found as the product of steady-state oxygen consumption and the time constant of the exponential rise (Whipp et al., 1982). During the deficit, mitochondrial respiration is supplemented through energy generated by creatine phosphate and glycolysis (Robergs and Roberts, 1997). The increase in oxygen consumption due to the slow component means that the oxygen deficit as a percentage of the total oxygen required increases as the work load increases above the anaerobic threshold (Whipp and Wassermnan, 1972).

Whenever there is a difference between the actual and required oxygen consumption, there is a deficit. As a trained person will reach steady state faster than an untrained individual, the trained person incurs less of an oxygen deficit. Performing a warm-up can also decrease the oxygen deficit (Robergs and Roberts, 1997).

When a steady-state can be reached, the oxygen deficit is the difference between steady state and non-steady state oxygen consumption. However, a deficit may occur also when a respirator is worn. Respirators have been shown to cause hypoventilation (Johnson et al., 1999; Caretti et al., 2001), so a respirator wearer has a lower minute ventilation and thus a lower oxygen consumption than that required by the body. The greater the deficit, the shorter the performance time.

Respiratory Work Rate

"It has long been assumed that respiration is physiologically adjusted to yield optimum respiration ratio, ratio of inhalation time to exhalation time, expiratory reserve volume, dead volume, airways resistance, and airflow waveshape (Johnson, 1993)." These adjustments are especially important during exercise when there is a competition among the skeletal, cardiac, and respiratory muscles for the limited oxygen available. Because of the limited oxygen supply and the fact that respiratory work does not contribute to the activity being performed, it is logical that respiratory work should be minimized during exercise. Data taken during exercise support this contention (Johnson, 1993).

At rest, respiratory work accounts for 1-2% of the total oxygen consumption (Johnson, 1991). This increases up to 10% during exercise. Changes in airflow waveshape could have a significant effect in a model of respiratory work. Indeed, Yamashiro and Grodins (1971) found a 23% lower work rate for a rectangular waveshape compared with a sinusoidal waveshape. They used a simple model that had only had one resistance and one constant compliance.

Respiration occurs with different flow patterns that depend on exercise intensity. At rest, inhalation has a sinusoidal waveshape while exhalation occurs with an exponential waveshape. Both inhalation and exhalation waveforms are trapezoidal with rounded corners during moderate exercise. Inhalation waveforms remain trapezoidal during heavy exercise, but exhalation waveforms return to an exponential shape.

At rest, both inhalation and exhalation waveshapes appear to be unrelated to work rate. Yamashiro and Grodins (1971) found that the sinusoid resulted from a mean squared acceleration criterion. They reasoned that the sinusoidal waveshape resulted in improved gas transport efficiency and a uniform ventilation of the lungs.

The resting exponential exhalation waveshape is due to passive exhalation. There is little muscle activity required during exhalation at rest. The energy comes instead from elastic energy stored in the chest wall, which is expanded during inhalation. Additional energy comes from air that is compressed in the lungs during inhalation.

During moderate exercise, both inhalation and exhalation are active. The trapezoidal waveshapes appear to be related to respiratory work rate, although they differ from the rectangular waveshape that minimizes respiratory work (Yamashiro and Grodins, 1971; Johnson and Masaitis, 1976). Both Hamalainen and Sipila (1984) and Ruttiman and Yamamoto (1972) gave possible reasons for the trapezoidal shape. Hamalainen and Sipila (1984) got a trapezoidal waveform when they included an additional term in their optimization criteria that is equal to the square of muscular pressure times the volumetric flow rate. This term accounts for the decreased muscular efficiency seen at higher loads. Ruttimann and Yamamoto (1972) also obtained a trapezoidal waveform, although the slope was in the opposite direction. Their waveform resulted when they minimized respiratory work while using an airways resistance that increased as volume decreased. Johnson (1986) found that a part of lower airways resistance has this inverse effect. The reason for the rounded corners may be that rapid accelerations are penalized to avoid damage or loss of control (Johnson, 1991; Johnson, 1993). Or, the rounded corners may indicate that the strength of the respiratory muscles is limited (Johnson, 1993).

The same inhalation optimization criteria during moderate exercise is in effect during heavy exercise (Johnson, 1991). Thus, the waveshape remains trapezoidal. The exhalation waveshape returns to exponential although the reason for the exponential waveform differs from that at rest. During heavy exercise, exhalation flow rate is limited. Johnson and Milano (1987) plotted transpulmonary pressure against expiratory flow rate along lines of equal lung volume. They found that a point was reached beyond which the flow could not be increased. The limiting flow rate was inversely related to the lung volume. The very abrupt transition to the exponential waveform only occurs during a maximal effort when the respiratory system is extremely taxed (Johnson and Milano, 1987; Johnson, 1993). Because flow rates and respiratory muscle pressure were so high, much more energy was required by the exponential waveform (Johnson, 1993).

There is one other characteristic of the moderate and heavy exercise waveforms that needs to be discussed. There are dimples that often appear in the waveforms. The reason for these dimple is not clear (Johnson, 1991). However, when minimizing the Hamalainen and Viljanen (1978) inhalation optimization criteria, the dimples appear in the waveform under certain conditions (Johnson, 1991).

Respiratory Work Rate Model

The work rate of breathing with different waveshapes was investigated by Johnson (1993). The model of the respiratory airways that was used contained a small number of elements with nonlinearities resulting from the airways and mask (Johnson, 1992). The model used the modified Rohrer equation:

$$p = K_1 \dot{V} + K_2 \dot{V}^2 + \frac{K_3 \dot{V}}{V} + \frac{V - V_r}{C} + I \ddot{V} \qquad (39)$$

where p = respiratory muscle pressure, $\mathrm{N/m^2}$

$\dot{V}$ = respiratory flow rate, $\mathrm{m^2/sec}$

V = lung volume, $\mathrm{m^3}$

$\ddot{V}$ = volume acceleration, $\mathrm{m^3/sec^2}$

V_r = resting volume of the lung, $\mathrm{m^3}$

K_1 = first Rohrer coefficient for the respiratory system, $\mathrm{N{\cong}sec/m^5}$

K_2 = second Rohrer coefficient, $\mathrm{N{\cong}sec^2/m^8}$

K_3 = “third” Rohrer coefficient, $\mathrm{N{\cong}sec/m^2}$

C = respiratory compliance, $\mathrm{m^5/N}$

I = respiratory inertance, $\mathrm{N{\cong}sec^2/m^5}$

This model was sufficient for both inhalation and exhalation if different values were used for the parameters K_1 to K_3, C, and I (Johnson, 1992). An extra term must be added when flow rate nears maximum exhalation flow rate (Johnson, 1993):

$$p_e = K_1\dot{V} + K_2\dot{V}^2 + \frac{K_3\dot{V}}{V} + \frac{V - V_r}{C} + I\ddot{V} + \frac{K_4}{\left(1 - \frac{\dot{V}}{\dot{V}_L}\right)} \tag{40}$$

where p_e = respiratory muscle pressure at airflow limitation, N/m^2

K_4 = additional coefficient, N/m^2

$\dot{V}_L$ = limiting flow rate, m^3/sec

Waveshapes. Johnson (1993) developed the equations for the respiratory work rates when breathing with a sinusoidal, rectangular, truncated exponential, hybrid exponential, and trapezoidal breathing pattern. Linear, quadratic, volume dependent, compliant, and inertial pressure terms were included.

Variable Lung Volume. The expiratory reserve volume changes during exercise thus changing the initial lung volume. The correct lung volume needs to be included in the volume dependent and compliant work rate terms. For the volume dependent term, the correct volume is simply inserted into the formula. For the compliant term, it was not necessary to change the equation as long as exhalation was active and the whole breathing cycle was considered. This was because the added term would be the same magnitude but opposite sign for inhalation and exhalation, thus canceling its effect.

Maximum Expiratory Flow. Expiratory flow rate can become limited during maximal exertion. This limitation can cause respiratory distress and early termination of exercise for people wearing respirators (Johnson and Berlin, 1974).

A term for maximum respiratory rate of work must be added to the limited flow hybrid exponential work rate equations (Johnson, 1993):

$$\dot{W}_R(6) = \frac{1}{T}\int_0^T p_{\max}\,\dot{V}_L\,dt \qquad (41)$$

where $\dot{W}_R(6)$, average respiratory work rate during flow limitation,
N·m/sec
T, duration of waveform, sec
t, time, sec

Effect of Waveshape on Respiratory Work Rate. The work rate while breathing with each of the five waveshapes was investigated during rest and light, moderate, heavy, and very heavy exercise. The lowest work rates occurred with the rectangular waveform. Comparisons were made to the rectangular waveform. The increased cost of the sinusoid for inspiration ranged from 9% at light exercise to 16% at very heavy exercise. The inspiratory trapezoid had an increased cost of 3% at light exercise and 7% during heavy exercise. The truncated exponential costs 30% more at light exercise and 9% during heavy exercise for inspiration. Finally, the hybrid exponential for inspiration was 29% higher for light exercise and 12% higher during very heavy exercise. For exhalation, the work rates were lower than for inhalation because of longer inhalation times.

Waveform Transition

Little work has been done on the transition between waveshapes during exercise. This is important, because as shown in Johnson (1993), the work rate is dependent on the breathing waveform.

Hamalainen and Viljanen (1978) developed a model of the control of the breathing pattern during respiration based on optimization criteria. The performance criteria were chosen to minimize the oxygen cost of breathing. Both criteria have an average square of volume acceleration term. The inspiratory criterion is the weighted sum of that term and the mechanical work performed by the inspiratory muscles. The expiratory criterion includes an integral square driving pressure in place of the mechanical work term.

For inhalation, the authors found that when the ratio of pressure times flow to the square of volume acceleration became large, a transition occurred from a sinusoidal to a trapezoidal waveform. Similarly for exhalation, when the ratio of pressure squared to volume acceleration squared became large, the waveshape changed from exponential to trapezoidal.

Their method is not practical for this model because the weighting functions, α_1 and α_2, are specific to the individual being tested and have no known physiological basis. The authors noted that different alpha parameters made sense because "the airflow patterns of any given individual look as unique as fingerprints (Hamalainen and Viljanen, 1978)." But, this means that each person must be tested and the actual breathing waveforms compared to the predicted waveforms. The weighting functions are adjusted until the differences between the two sets of waveforms are minimal. A better means is necessary to determine when transitions in the respiratory waveforms occur.

Respiratory Protective Masks

Respiratory protective devices have a profound impact on the wearer. Vision, communications, and personal support (wiping of nose, drinking) are all hindered. Problems occur due to sweat accumulation inside the mask and reduced heat loss through the mask. Sore neck muscles and skin irritation become a concern with extended wear. The physical characteristics of the respirator, the inspiratory and expiratory resistance, the dead volume, and the weight, affect the physiological response and impede performance. The influence of each of these factors depends in part on the work intensity and the type of task. Other important factors to consider are variability, anxiety, and hypoventilation.

Physical Characteristics

Resistance. A person wearing a mask must overcome the resistance to breathing caused by the filter and the inspiratory and expiratory valves in the mask. A number of studies have investigated the effects of external resistance on pulmonary function.

Flook and Kelman (1973) investigated the effects of increased inhalation resistance on seven subjects exercising on a bicycle ergometer for ten minutes at 35, 50, and 70% of V_{O2max}. The inhalation resistances were 8.9, 16.5, and 53.1 $cmH_2O/L/s$ measured at a steady flow of 1 L/s. These resistances were chosen to represent resistances seen in patients with pulmonary disease. Regression equations fit to their data showed that minute ventilation decreased with increased resistance. The slope coefficients for these equations for work done at 35, 50, and 70% V_{O2max} were –0.0023, -0.005, and –0.0214, respectively. Regression equations fit to the tidal volume data indicated that at 35%V_{O2max}, the tidal volume increased with increased resistance while tidal volume was virtually unaffected by resistance at the other two work rates (r = 0.05 and r = 0.005). The slopes of these equations in order of increasing work rates were 0.0078, 0.0011, and 0.0009, respectively.

The effects of three inhalation resistances on subjects performing steady-state bicycle exercise was investigated by Demedts and Anthonisen (1973). Exercise periods lasted five minutes if possible or three minutes when the work load could not be tolerated for the full five minutes. The work loads were 82, 131, 196, 245, and 270 W. The resistances read off a pressure-flow graph at approximately 1.4 L/s were 1.6, 3.1, and 12.4 cmH_2O/L/s. The dead space for all conditions was 350 mL. The authors found that minute ventilation was not decreased by the lowest resistance. A statistically significant 12% decrease occurred for the middle resistance at the highest work load while the highest resistance caused a 50% decrease at the higher work rates.

Silverman et al. (1951) investigated the effects of two combinations of inhalation and exhalation resistance on 18 healthy males during bicycle exercise at constant rates of 0, 34, 68, 102, 136, 181, 226, and 271 W. Not all subjects completed all conditions. Data were recorded at six, eight, and ten minutes into the exercise. The inhalation and exhalation resistances were 0.4 and 0.2 cmH_2O/L/s for the low condition, and 4.5 and 2.9 cmH_2O/L/s for the high condition. A third condition was tested at the 68 W work rate only. The inhalation and exhalation resistances for this condition were 4.5 and 1.9 cmH_2O/L/s. The authors found that the minute ventilation was reduced almost 20% at the highest two work rates. The authors stated that the resistance used did not affect tidal volume at work rates below 181 W. The percent change in the minute ventilation, respiratory rate, and tidal volume from the low to high resistance conditions was determined at each work rate. Tidal volume was determined by dividing the mean minute ventilation by the mean respiratory rate. The results are shown in Table 2.

Table 2. Percent changes in minute ventilation, respiratory rate, and tidal volume from the low to high resistance conditions. Data are from Silverman et al. (1951).

	V_E (L/s)	RR (b/s)	V_T (L)
	% change	% change	% change
Rest	-13.2	1.4	-14.7
0	-7.6	-12.0	4.0
34	-5.1	-13.4	7.3
68	-10.7	-9.7	-1.0
102	-3.0	-2.2	-0.8
136	-11.9	-10.9	-0.8
181	-16.9	-7.1	-9.2
226	-27.9	-19.0	-7.5
271	-26.0	-13.3	-11.2

It can be seen from the table that tidal volume was affected at low work rates. In fact, the tidal volume increased at the two lowest work rates. At work rates of 68, 102, and 136 W, the tidal volume does not appear to be affected by the resistances used. At work rates above 181 W, the tidal volume decreased with added resistance.

Cerretelli et al. (1969) assessed the effects of two resistances on two subjects during treadmill exercise at work rates ranging from about 70 to about 210 cal/kg min. Subjects inhaled and exhaled against the same two resistances of 8.5 and 16.9 cmH$_2$O/L/s. The minute ventilation for the two subjects decreased at all work rates as the resistance increased.

Hermansen et al. (1972) investigated the effects of a respirator mask and breathing valve on minute ventilation and tidal volume on ten healthy subjects performing on a bicycle ergometer at work rates of 49, 98, 147, and 196 W. The inhalation and exhalation resistances of the mask were 9 and 2.6 cmH$_2$O/L/s, respectively while those of the valve were 1.7 and 1.7 cmH$_2$O/L/s.

Minute ventilation was always lower with the mask than with the valve. At the highest work load, the decrease in minute ventilation was 43%. Tidal volume was greater with the mask up to a minute ventilation of approximately 70 L/min. After that, tidal volume decreased with added resistance.

The effect of inspiratory resistance on breathing parameters was investigated by Caretti and Whitley (1998). Subjects exercised on a treadmill at 80-85% of V_{O2max} while wearing a half-respirator with one of four inspiratory resistances ranging from 0.2 kPA to 0.49 kPa, measured at a steady airflow rate of 1.42 m/s. Treadmill speed and grade were adjusted for each resistance condition so that the subject was at 80-85% of V_{O2max}.

Tidal volume was shown to be relatively constant across the respirator conditions. No significant differences among the conditions were found. The differences from the control condition were +1%, 0%, +1.1%, and –2.7% for the R1, R2, R3, and R4 conditions respectively. However, minute ventilation decreased as resistance increased. The differences were significant between the control and R4 conditions. The decreases in minute ventilation from the control condition were 2.4%, 9.8%, 14.9%, and 35.4% for the R1, R2, R3, and R4 conditions respectively.

Johnson et al. (1999) quantified the effect of increased inhalation resistance on minute ventilation. Twelve subjects exercised at 80-85% V_{O2max} until their volitional end-point while wearing a U.S. Army M-17 respirator with one of six different inhalation resistances. Plugs with different size holes bored through the center were placed in the inhalation ports to modify the resistance. The inhalation resistances were 0.78, 1.64, 2.73, 3.32, 6.47, and 7.64 cm H_2O/L/s at a flow of 1.42 L/s (85 L/min). The exhalation resistance for all tests was 1.3 cm H_2O/L/s. The relationship between minute volume and inhalation resistance was found to be:

$$V_E = -0.0687 \cdot R_{inh} + 1.325 \qquad (42)$$

where: V_E, minute volume, L/s

R_{inh}, inhalation resistance, cmH_2O/L/s

A similar study was conducted to examine the effect of increased exhalation resistance on work performance and ventilation (Caretti, et al., 2001). Subjects wore a U.S. Army M40 respirator with one of five exhalation resistances while exercising on a treadmill at 80-85% V_{O2max}. The exhalation resistances were 0.47, 1.81, 4.43, 12.27, and 27.35 cm H_2O/L/s. The inhalation resistance for all conditions was 3.17 cm H_2O/L/s. Lower minute volumes were found for increasing exhalation resistance:

$$V_E = -0.0299 \cdot R_{exh} + 1.2365 \qquad (43)$$

where: V_E, minute volume, L/s

R_{exh}, exhalation resistance, $cmH_2O/L/s$

So, in both cases (Johnson et al., 1999; Caretti et al., 2001), as resistance increased, minute volume decreased. The effects of the inhalation resistance were three times that of the exhalation resistance (Caretti et al., 2001).

The above studies indicated that at all work rates, inhalation and exhalation resistance caused a decrease in minute ventilation. Only one study contradicted this. Demedts and Anthonison (1973) found that minute ventilation was not decreased at their lowest resistance.

Flook and Kelman (1973), Hermansen et al. (1972), and data from Silverman et al. (1951) indicated that at low work rates tidal volume was increased by resistance. Resistance at higher work rates has been reported to not have an effect on tidal volume (Flook and Kelman, 1973; Caretti and Whitley, 1998) or to decrease tidal volume (Silverman et al., 1951; Hermansen et al., 1972).

In addition to increasing the inhalation and exhalation resistance, the valves also require an additional amount of pressure to open the valves. Cummings (1968) investigated the pressures required to open the valves in an M17 mask. The inspiratory pressure was found to be:

$$p_i = 3.227x10^5 \dot{V} + 5.609x10^7 \dot{V}^2 \tag{44}$$

where p_I, inspiratory pressure inside the mask, N/m^2

$\dot{V}$ = flow rate, m^3/sec

The expiratory pressure for the same mask was (Cummings, 1968):

$$p_e = 59.93 + 6.629x10^4 \dot{V} + 1.376x10^7 \qquad (45)$$

where p_e, expiratory pressure inside the mask, N/m^2

$\dot{V}$ = flow rate, m^3/sec

The constant term in the p_e equation is the pressure needed to open the valve. This results in an addition to the respiratory work rate (Johnson, 1992):

$$\dot{W}_R(7) = 0.05 p_o \dot{V}_{max} T(1 + e^{-0.8T/\tau}) \qquad (46)$$

where $\dot{W}_R(7)$, respiratory work rate due to constant pressure term, W

$p_{o,}$ constant term, N/m^2

$\dot{V}_{max}$, maximum flow rate during breathing waveform, m^3/sec

T, waveform duration, sec

τ, respiratory time constant, sec

Dead Volume. Dead volume, or dead space, is the amount of air present that does not take place in respiration, including air in the nasal passages and throat. This volume is increased when an object, such as a snorkel, mask, or breathing tube, is placed over the mouth and/or nose. Carbon dioxide accumulates in the dead volume, causing it to act as a respiratory stimulant.

As airflow increases, so does dead volume. This occurs because when the flow rate increases, the airflow becomes more turbulent, causing a greater mixing of gases. Thus, air that was trapped at corners and around objects becomes mixed with the airflow, increasing the dead volume. The volumetric space inside a respirator is termed the nominal dead volume while dead space as a function of tidal volume is termed effective dead volume.

Breathing through an external dead volume causes a performance decrement. Johnson, et al. (2000) investigated this effect by having subjects walk on a treadmill at 80-85% VO2max with respirator configurations giving a range of dead volumes. While performance time was affected, no effect of dead volume on minute ventilation, tidal volume, or oxygen consumption at termination was found.

Stannard and Russ (1948) studied the effects of increasing dead volume on minute ventilation and tidal volume for seven subjects at rest and during light exercise. The light exercise was chosen as the work rate at which the resting oxygen consumption doubled. No indication of V_{O2max} was given. Nominal dead spaces of 250, 350, 420, 450, and 540 mL were used.

At rest, the tidal volume increased as dead volume increased. During light exercise, tidal volume increased with added dead volume, but the changes were smaller. For the lowest dead volume, the change in tidal volume was not significant.

The minute ventilation increased with added dead volume for resting and lightly exercising subjects. The authors noted that the regression lines fit to the data had similar slopes. The near constant difference between the two lines was reported to be approximately 2 L/min.

In 1980, Ward and Whipp studied the effects of dead volume on minute ventilation of three subjects. The authors concluded that minute ventilation increased during rest and moderate exercise as a result of added dead space.

The three studies noted above only looked at rest, light exercise, and heavy exercise. Harber and colleagues have completed a number of studies in which they investigated the effects of inhalation resistance and dead volume on breathing parameters at rest and during moderate exercise. Unfortunately, most of their information can not be used in a model. In one study (Shimozaki et al., 1988) only subjective responses were reported. In another study (Harber et al., 1982) subjects were allowed to pick their own work rate so that it was consistent with long-term work. Finally, three studies (Harber et al., 1984; Harber et al., 1988; Harber et al., 1990) were conducted in which one load, a combination of inhalation resistance and dead volume, was applied. The effects of the resistance and dead volume on the breathing parameters could not be separated.

Mass and Load Placement. The mass of the mask will increase the external work rate. The equation developed by Pandolf et al. (1977) and the external work rate equation presented by Aoyagi et al. (1995) included total mass (body mass plus load mass) in the calculations. If the external work is specified and not calculated, the external work rate without the mask will be increased. The increase will equal the percentage increase in mass represented by the mask. Thus, a typical mask has a mass equal to 1.4% of the normal body mass of a man. The work rate for that mask would be increased by 1.4% to account for the added mass of the mask.

The respirator mass is not distributed evenly over the head. An eccentricity factor takes into account this fact.

Other Factors

Variability. The variability in response to respirators wear across the population underscores the necessity of using large sample sizes in conducting studies and in calibrating and validating models. The study by Johnson et al. (1999) showed that three of the twelve subjects were not sensitive to inspiratory resistance and indeed showed little performance decrement. A study examining the effects of exhalation resistance (Johnson, et al., 1997) found that three of ten subjects could perform no treadmill work when the resistance was very high, but that the other seven were able to perform for two to ten minutes. Finally, the performance of subjects who scored an anxious rating on the Spielberger State-Trait Anxiety Test was dependent on the numerical score, while those classified as non-anxious had performances unrelated to their score.

Anxiety. Psychological factors can play a large role in whether or not a person can tolerate respirator wear. To determine the amount of influence such factors have, Johnson, et al. (1995) conducted a exercise study in which subjects took the Spielberger State-Trait Anxiety Inventory (STAI) to assess their anxiety level.

Twenty subjects exercised at 80-85% of their age-predicted maximum heart rate until their volitional end-point. The performance times of subjects classified as non-anxious (STAI scores less than 34) were unrelated to the STAI score. However, for anxious subjects, the performance rating was related to the anxiety score. Someone with a STAI score of 40 would suffer a 25% decrement in performance. A highly anxious person (STAI score of 70) would have a 79% decrement and would therefore only achieve a 21% performance rating.

Hypoventilation. Hypoventilation is a condition in which the subject is breathing at a lower minute volume than normal. This may be due to either more shallow breaths or less frequent breaths, or both. The hypoventilating person must extract more oxygen from each breath as the oxygen requirements of the body are unaffected by the decreased minute volume. As less air is exhaled during hypoventilation, the carbon dioxide concentration in the exhaled air must increase. Thus, high concentrations of carbon dioxide and low concentrations of oxygen in the exhaled air indicate that a person is hypoventilating. Hypoventilation has been evident in two respirator studies. The first study (Johnson, et al., 1995) involved incremental bicycle exercise while wearing an M17 respirator. Hypoventilation was indicated by high F_{ECO2} and low F_{EO2} values during respirator wear.

Subjects participating in a study on the effects of inspiratory resistance on performance time also evidenced hypoventilation (Johnson et al., 1999). Subjects had decreasing minute volumes and oxygen consumption as resistance increased.

OBJECTIVES

The objectives of this research were to:

1. Develop the structure for a model of the effects of respiratory protective masks on humans during physical activity;

2. Develop equations for the model structure; and

3. Combine the model equations into a tool to aid respirator designers by implementing the model in a high-level programming language.

EQUIPMENT

Experimental Testing

Experimental testing was conducted in the Human Performance Laboratory at the University of Maryland College Park. The testing system consisted of a treadmill, gas collection system, respiratory protective mask, and heart rate monitor.

Treadmill

Subjects exercised on a Quinton Q65 treadmill (Quinton Instrument Co., Bothell, WA) with allowable speeds of 0.58 m/s to 7.83 m/s (1.3 mph – 17.5 mph) and grades of 0 to 25%. Three subjects used a 22.5 cm high step-stool (Brewer Quality Health Care Equipment, Menomonee Falls, WI) for the lowest work rate.

Gas Collection System

Expired air from the subjects passed through a breathing tube (Warren E. Collins, Braintree, MA) into a 3L mixing chamber and then through a heated Fleisch Number 3 pneumotach (OEM Medical, Richmond, VA). Inhaled air passed through the heated pneumotach into separate tubing connected to the inhalation side of the respirator. Exhaled oxygen and carbon dioxide concentrations were sampled from the mixing chamber by a Perkin-Elmer (Pomona, CA) MGA 1100 mass spectrometer.

The pneumotach was connected to a Validyne DP-15 differential pressure transducer (Validyne, Northridge, CA) and Validyne CD-12 transducer indicator. The signal from the transducer indicator was split to two separate computers equipped with DAS-8 (Keithley Data Acquisition, Taunton, MA) data acquisition boards.

The program PNEUMO (Johnson and Dooly, 1993) was run on one computer and was used to collect minute volume, tidal volume, respiratory rate, inhalation time, and exhalation time. A second computer was used to run VO2_2000, a program developed in the Human Performance Laboratory that provided exhaled concentrations of carbon dioxide and oxygen, minute ventilation, tidal volume, and relative and absolute oxygen consumption. The output port on the mass spectrometer was connected to the DAS-8 board on the second computer.

For the maximal oxygen consumption test and levels determination session, subjects used a Hans-Rudolph, Inc., (Kansas City, MO) 2700 series adult large one-way non-rebreathing valve and either a half-mask (Hans-Rudolph Mouth/Face Mask) with head harness (Hans-Rudolph Head Cap Assembly) or bite-block mouthpiece and nose-clip. Each subject used the same type of equipment (half-mask or mouthpiece) for both the maximal oxygen consumption test and the session during which treadmill speeds and grades were determined to elicit the target intensity levels.

Respiratory Protective Masks

Subjects wore a U.S. Army M-40 full-facepiece respirator for each of the respirator conditions. The M-40 is a negative pressure, air-purifying respirator that has a molded rubber facepiece and an elastic headharness. The right inhalation port was closed off. An adapter was screwed into the left inhalation port to allow plug resistances to be placed in the flow path. An 86 cm long, 3.5 diameter flexible tube with a PVC adapter was placed over the exhalation port of the mask. Plug resistances with hole diameters of 11mm and 8 mm were used on the inhalation side in addition to the standard inhalation valve in the respirator. Exhalation resistances were either the standard or step (non-standard) flap valves for the M-40 respirator.

Three resistance combinations were used. Respirators A, B, and C had inhalation and exhalation resistances of 0.88 and 1.69, 1.84 and 1.69, and 5.73 and 1.01 cmH_2O/L/s measured at a steady flow of 1.42 L/s. The approximate nominal dead volume was 300 mL.

Heart Rate Monitor

Heart rate was monitored using a 3-lead electrocardiogram (ECG) (Component Monitoring System, Hewlett Packard, Palo Alto, CA).

Software

In addition to standard word-processing and spreadsheet software, two software packages were used in this research. Statistical analyses were performed using SPSS/PC+ Studentware Plus (SPSS, Inc., Chicago, IL) statistical package. The model was programmed in Visual BASIC 6.0 (Microsoft Corporation, Redmond, WA) on a Pentium 133MHz computer.

PROCEDURE

The development of the model occurred in four stages. The first stage involved establishing the structure of the model. In the second stage, experimental data were obtained for use in stage three. Equations were developed to fill the model structure during stage three. The fourth stage involved implementing the model in Visual BASIC and evaluating the results.

Structure of the Model

The intent of the model was considered in developing the structure of the model. The desired outputs were selected first. Required inputs were then chosen. The steps needed to proceed from the inputs to the outputs were specified. A flow chart was developed.

Experimental Testing

Five male and three female subjects between the ages of 23 and 38 were recruited for the study. All subjects were either students at the University of Maryland College Park or had participated in prior testing in the Human Performance Laboratory. The protocol was approved by the University of Maryland Institutional Review Board (see Appendix A).

Prior to participating in the study, subjects filled out a detailed medical history questionnaire and PAR-Q to determine if there were any medical conditions or medications that would preclude their participation in the study. Prospective subjects completed the Speilberger Trait Anxiety Inventory (Speilberger, 1983). Prospective subjects who scored a 45 or higher were excluded due to the possibility that they would exhibit anxiety while wearing the respirator. Two subjects who scored just above 45 (46 and 48) were included as they had participated in prior respirator research studies without difficulty. All subjects received a verbal description of the study and signed an informed consent document prior to the start of testing.

All testing procedures were conducted at ambient room temperature (22-23°C) in an environmentally controlled laboratory to minimize environmental influences on the data. Each subject was instructed to get adequate rest the night before each test, to eat breakfast or lunch, and to drink plenty of fluids, excluding alcohol and caffeine, before reporting to the laboratory. Prior to each test session, the subject was questioned to insure that no condition existed in the subject that would jeopardize his/her safety or health. Examples of such conditions would be an upper respiratory tract infection, excessive fatigue, or musculoskeletal injuries. Individuals who reported such conditions were rescheduled at another time after they had fully recovered from their ailment. Subjects were clothed in their own T-shirt, shorts, socks, and sneakers for all exercise trials. At least two personnel certified in cardiopulmonary resuscitation were present for all testing.

Prior to the start of the test trials, each subject completed a test to determine maximal oxygen consumption using an incremental treadmill exercise protocol.

Subjects wore either a mouthpiece and noseclip or a Hans Rudolph half-mask for the testing. The tests was terminated if any of the following conditions occurred: oxygen consumption changed by less than 200 ml/min with increasing workrate, respiratory exchange ratio exceeded 1.0, a maximal age-predicted heart rate was achieved, or a rating of perceived exertion (RPE) greater than 17 (very hard) was given. Heart rate, electrocardiogram, and RPE were monitored during V_{O2max} testing.

Subjects returned to the laboratory to determine the treadmill speed and grade required to elicit the following intensity levels: 25-30, 35-40, 45-50, 65-70, and 80-85% of maximal oxygen consumption. For three subjects, oxygen consumption was greater than 25-30% at the lowest treadmill speed of 0.58 m/s and 0% grade. The lowest work rate for these subjects was done on a 22.5 cm high step-stool instead of the treadmill. Heart rate, ECG, tidal volume, minute volume, oxygen consumption, and RPE were monitored during this session.

Three conditions of submaximal exercise testing were randomly assigned. Subjects exercised on the treadmill at each of the five intensity levels while wearing one of three respirators. The three respirators were: U.S. Army M-40, full-facepiece respirator with standard inhalation (0.88 $cmH_2O/L/s$) and exhalation (1.69 $cmH_2O/L/s$) valves; U.S. Army M-40, full-facepiece respirator with inhalation and exhalation resistances of 1.84 and 1.69 $cmH_2O/L/s$; and U.S. Army M-40, full-facepiece respirator with inhalation and exhalation resistances of 5.73 and 1.01 $cmH_2O/L/s$. All resistances were measured at a constant flow of 85 L/min (1.42 L/s).

Prior to the start of each exercise session, subjects completed a five-minute warm-up period of walking on the treadmill. The treadmill was then stopped so the subject could stretch. The subject was then seated and donned the respirator. Resting data was taken while the subject was seated. Subjects began exercising at 25-30% of V_{O2max}. After a steady-state was achieved, the exercise intensity was increased to 35-40% of V_{O2max}. This continued with exercise intensity increasing to 45-50%, 65-70%, and 80-85% of V_{O2max}. Eleven of the twenty-four trials were conducted in this manner. Because of concerns that increased body temperature and oxygen drift might have been causing higher than expected oxygen consumption, the remaining subjects and trials were conducted with a slight modification. Between the third (45-50%) and fourth (65-70%) stages and between the fourth and fifth (80-85%) stages, the treadmill was stopped and the subject remained seated until oxygen consumption and heart rate returned to resting values. Subjects were given a cool-down at the end of the stage prior to stopping the treadmill and were given a warm-up prior to the subsequent stage. The time to return to baseline readings varied between subjects and depended on exercise intensity. The time the subjects were seated between stages ranged from one to five minutes. Heart rate, ECG, tidal volume, minute volume, oxygen consumption, and RPE were monitored during each testing session. The State-Anxiety test (Spielberger, 1983), a measure of situational anxiety, was administered before and after each treatment session.

Subject Information

Subject demographics were reported.

Determining Steady-State Minute Ventilation and Tidal Volume

Before steady state minute ventilation and tidal volume were obtained, the work rates were checked and the possibility of the occurrence of oxygen drift was investigated. Subject variability was assessed also.

Targeted Work Rates.Oxygen consumption data from the levels determination sessions were analyzed for each subject to ensure that subjects were working at the targeted work rates.

Evaluation of Oxygen Drift and Subject Variability. One subject repeated the standard respirator condition three times to determine the variability in subject responses and to determine if oxygen drift was occurring. All data from stage five were plotted and a linear equation fit to the last four minutes of data (8 points). A Student's t-test was performed to determine if the slope was significantly different from zero.

Steady-State Values. Oxygen consumption, minute ventilation, and tidal volume data for the four combinations of inhalation and exhalation resistance were analyzed to determine steady-state values. The last three minutes of data (6 points) from each stage were averaged to determine the steady-state value for the subject and respirator condition. The data from the eight subjects were averaged so that an average tidal volume and minute ventilation for each stage and each respirator condition were obtained. Standard deviations were obtained also.

Development of Equations

The equations needed for the model structure were established. In some cases, existing equations were used. Where equations were not available, new equations were developed.

The specific statistical procedures used to develop each equation are discussed with each equation. In general, the following statistical analysis was performed. The data were plotted and the relationship between the variables observed. A regression equation was calibrated using the method of least squares. The standard error ratio, standard error of the coefficients, the correlation coefficient, partial regression coefficient, bias and mean bias were determined. The residuals were plotted and examined for any patterns. Percentage errors in the predictions were determined and discussed. When sufficient data were available, a regression equation was fit to validation data. A Student's t- test (hereafter referred to as a t-test) was performed to determine if the coefficients in the validation equation were equal to the coefficients in the calibration equation. The significance level was $\alpha = 0.05$. If sufficient data were not available for validation, the available data were plotted along the calibration regression equation and the percent errors in prediction obtained.

External Work Rate

Equations for determining the external work rate for various activities were selected.

Efficiency as a Function of External Work Rate

The equations developed by Johnson (1992) for positive work rates were used. A graph of efficiency versus positive work rate was obtained. Data was obtained from Webb et al. (1988), Nagle et al. (1990), and Hambraeus et al. (1994). The data from these studies were plotted on the graph of efficiency versus positive work rate from Johnson (1992). The fit of the data to the equation was assessed using residuals and percent error. Bias and mean bias were determined also.

Equations for negative efficiency were obtained. Data from Nagle et al. (1990) were used to assess the equation. A plot was obtained of negative efficiency versus negative external work rate along with the data from Nagle et al. Residuals, percent errors, bias and mean bias were calculated.

A linear regression equation was fit to the data in the region where the Johnson (1992) equations did not fit well. A plot of the data points and the best fit equation were obtained.

Johnson (1992) specified the bounds for each of the four efficiency equations as the points where the equations intersected. Because one of the equations was changed, the bounds of the equations for the other regions were changed. The point at which the linear regression equation intercepted the equation at the upper and lower bounds was taken as the new upper and lower bound for that region. The new efficiency equations were determined and were plotted with the data from Webb et al. (1988), Nagle et al. (1990), and Hambraeus et al. (1994). Residuals, percent errors, bias, and mean bias were determined and compared to the statistics from the previous equations.

Equations for negative efficiency versus external work rate were obtained by multiplying by −2 the efficiency for positive external work rate determined from the Johnson (1992) equations. The old and new equations for negative efficiency were plotted with the data from Nagle et al. (1990). Residuals, percent errors, bias, and mean bias were calculated. Statistics from the new and old equations were compared.

Data from Luthanen et al. (1987) and Gaesser and Brooks (1975) were plotted together with the new equations. Percent errors were used to evaluate the fit of the model to the data.

Physiological Work Rate

The physiological work rate was calculated from the external work rate and efficiency.

Oxygen Consumption

Oxygen consumption and respiratory exchange ratio data from Carle (1980) were obtained. Physiological work rate was calculated using the Lusk (1928) equation. The data were randomly sorted. The random number generator in Microsoft Excel was used to generate a random number for each data point. The data points were sorted according to this random number. Two-thirds (340) of the data points were used for calibration while one-third (170) were used for validation.

Oxygen consumption was plotted versus physiological work rate and a linear regression performed. The data and regression line were plotted. Standard error ratio, correlation coefficient, bias, and mean bias were obtained. A t-test was performed to determine if the slope and intercept were significantly different from zero.

As the intercept was not significantly different from zero, a zero-intercept model was fit to the calibration data. A plot of the data and the regression line was obtained. The standard error ratio, correlation coefficient, bias, mean bias, partial regression coefficient, and standard error of the coefficient were determined. The residuals were plotted against the physiological work rate. The percentage errors were obtained.

The validation data were plotted and a linear regression with a zero intercept was performed. A t-test was done to determine if the slope of the validation equation was the same as the slope from the calibration equation. The critical t-value for 150 degrees of freedom and $\alpha = 0.05$ was 1.976. The null hypothesis was that the slopes of the calibration and validation equations were the same. The null hypothesis was accepted if the calculated t-value was less than ± 1.976.

Data from Cloud (1984) were plotted on the regression line. Percentage errors were determined.

Anaerobic Threshold

Data were obtained from studies published in the literature and from theses. Male and female, trained and untrained subjects were included. The data consisted of age, height, weight, BMI, AT% and AT, V_{O2max}-AT difference, and V_{O2max} in relative (ml/kg/min) and absolute (L/min) terms. The following studies were used for calibration: Balsom (1988), Bradley (1982), Caprarola (1982), Claiborne (1984), Dwyer and Bybee (1983), Gray (1981), Jones (1984), Robbins (1982), Weltman and Katch (1979), Weltman et al. (1978), and Johnson et al. (1999).

Linear regression equations relating the AT, AT%, and V_{O2max}-AT difference to relative and absolute V_{O2max} were obtained. Multiple regression equations relating the AT, AT%, and V_{O2max}-AT difference to age, height, weight, BMI, and relative or absolute V_{O2max} were obtained.

The two linear regression equations and two multiple regression equations with the highest correlation coefficients were selected for further statistical analysis. The standard error ratio, standard error of the regression coefficients, partial regression coefficients, and model bias were determined. The sign of the coefficients was checked for rationality. Plots of the residuals versus the independent variables were obtained. Percent errors of the model output were calculated. The number of points with errors greater than 20%, 40%, and 100% were determined. Because the number of data points differed among the equations, the percentage of points in the error ranges stated previously were calculated also. Based on the statistical analysis, one equation was selected.

Data from Caretti et al. (2001) and Powers et al. (1984) were used to validate the selected equation. Data from these studies were overlayed on a plot of the original data and the selected regression equation. The residuals were evaluated from this plot. Percent errors in the model predictions were determined.

Minute Ventilation as a Function of Oxygen Consumption

Data were obtained from the eight subjects who completed the current study. The data were obtained from the levels determination session, the initial test to determine the speeds and grades for stages one to five for the respirator conditions. A plot of minute ventilation versus oxygen consumption was obtained for each subject and a linear curve was fit to the data below the anaerobic threshold while an exponential curve was fit to the data above the anaerobic threshold.

The maximum minute ventilation (V_{Emax}) and maximum oxygen consumption (V_{O2max}) were determined from the V_{O2max} test. The steady-state minute ventilation (V_E) and oxygen consumption (V_{O2}) data were divided by the V_{Emax} and V_{O2max}, respectively, to get the percentage of V_{Emax} (%V_{Emax}) and V_{O2max} (%V_{O2max}).

The data were plotted. Linear, quadratic, exponential, and power models were fit to the data. The following statistics were obtained for each model: S_e/S_y, bias, mean bias, and correlation coefficient. The %V_{Emax} predicted by each model for 100% V_{O2max} was determined. Based on the statistics, one model was selected.

Two subjects from the current study completed the levels determination test but could not complete all the respirator conditions. The data from those two subjects were used to evaluate the fit of the model. The residuals and percent errors were obtained. The data were plotted on a graph with the selected equation.

Determining V_{Emax}. The highest minute ventilation (V_{Emax}) recorded during each subject's test of maximal oxygen consumption from the current study was obtained. A plot of V_{Emax} versus V_{O2max} was obtained. A linear regression was performed.

Based on the results of the above, V_{Emax} and V_{O2max} data were obtained from two other studies (Caretti et al., 2001; Johnson et al., 2001). Combining these data with the data from the current study yielded 30 data points. The data were sorted by V_{O2max} in ascending order. Every third data point was removed from the set and reserved for validation. The other two-thirds of the data were used for calibration.

A linear regression equation was fit to the pooled data. The following statistics were obtained: S_e/S_y, $S_e(b_0)/b_0$, $S_e(b_1)/(b_1)$, t_1, bias, and mean bias. A plot of the residuals was obtained.

The one-third of the data reserved for validation was plotted and a regression equation found. A t-test was performed on the slope and intercept coefficients to determine if they were statistically different from the slope and intercept obtained during calibration. There were 8 degrees of freedom. The critical t-value for $\alpha = 0.05$ for a two-tailed test was 2.306. The null hypothesis was that the slope (or intercept) coefficient from the validation equation equaled the coefficient from the calibration equation. The null hypothesis was accepted for $-2.306 \leq t \leq 2.306$.

Tidal Volume as a Function of Oxygen Consumption

Plots of steady state tidal volume versus steady state oxygen consumption were obtained from the levels determination test for each of the eight subjects in the current study. The shape of the relationship between the two variables was observed.

The maximum tidal volume was obtained from the V_{O2max} test and all steady state tidal volumes were expressed as $\%V_{Tmax}$. A plot of $\%V_{Tmax}$ versus $\%V_{O2}max$ was obtained for each subject.

The data from the eight subjects were pooled and plotted. Linear, quadratic, exponential, and power models were fit to the data and plotted. The S_e/S_y, bias, mean bias, percent error of the residuals, and correlation coefficient were obtained for each model. The $\%V_{Tmax}$ predicted by each of the four models for 100% of V_{O2max} was determined. Based on the statistics, one model was selected.

The data from two subjects who completed the levels determination session but who could not complete the rest of the tests were used to validate the model. The data were plotted on a graph with the selected equation. The residuals and percent errors were obtained.

Determining V_{Tmax} as a Function of V_{O2max}. V_{Tmax} values were obtained from the current study and from Johnson et al. (1999) and Caretti et al. (2001). The data were pooled and sorted by V_{O2max} in ascending order. Every third data point was removed from the data set and was put aside for validation. The remaining two-thirds of the data were used for calibration. A linear regression equation was obtained for the calibration data. The calibration data and regression equation were plotted. The standard error ratio, the standard error of the regression coefficients, partial regression coefficient for the slope, the bias, mean bias, and correlation coefficient were obtained. The residuals were plotted and the percent errors obtained.

A linear regression equation was fit to the validation data. The validation data and equation were plotted. A t-test was performed to determine if the slope and intercept coefficients of the calibration and validation equations were the same. The null hypothesis was that the coefficients were the same. For eight degrees of freedom (10 samples – 2 coefficients being fit) and $\alpha = 0.05$, the critical t-value was 2.306. The null hypothesis was accepted if the calculated t-values were within ± 2.306.

The Effects of Resistance on Minute Ventilation and Tidal Volume

Average minute ventilation and average tidal volume were obtained for each of the five stages and each of the three conditions. Multiple regression equations were obtained regressing average minute ventilation (or tidal volume) on inhalation and exhalation resistance. The standard error, correlation coefficient, and bias were obtained. Results were compared to the literature.

Change in Minute Ventilation with Dead Space

Minute ventilation and tidal volume data were obtained for rest and light exercise (Stannard and Russ, 1948) and heavy exercise (Johnson et al., 2000). Data from Stannard and Russ (1948) were read from their Figure 1. The actual values were not presented.

Linear regression equations were fit to the resting and light exercise data. Plots of the data and the regression lines were obtained. The following statistics were calculated: S_e/S_y, r, bias, mean bias, and residuals. The residuals were plotted against tidal volume.

A t-test was performed to determine if the slopes and intercepts of the regression equations were statistically different. For five data points, the degrees of freedom were three (5 – 2 coefficients being fit). The critical t value for $\alpha = 0.05$ for a two-tailed test was 3.182. The null hypothesis was that the slopes (or intercepts) were statistically the same. This hypothesis was accepted if the critical t value was between –3.182 and 3.182.

The average difference between the predictions made with the two regression equations was determined. The work rate as $\%V_{O2max}$ was estimated for rest and light exercise. An equation relating the change in minute ventilation to dead volume and $\%V_{O2max}$ was obtained. The multiple regression equation was evaluated using the light and heavy exercise data. Residuals and percentage errors were obtained for the light exercise data.

Change in Tidal Volume with Dead Space

Tidal volume and dead space values for rest and light exercise (Stannard and Russ, 1948) and heavy exercise (Johnson et al., 2000) were obtained. Linear regression equations were fit to the rest and light exercise data and the following statistics were obtained: S_e/S_y, r, bias, relative bias, and percent errors. The data and regression lines were plotted. Plots of the residuals versus dead volume were obtained.

Work rates were estimated for rest and light exercise and were expressed as percentages of maximal oxygen consumption. A multiple linear regression equation was fit to the data and the following statistics obtained: S_e/S_y, r, bias, relative bias, and percent errors. Plots of the residuals versus $\%V_{O2max}$ and dead volume were obtained. The regression equation was checked for rationality of predictions.

Oxygen Consumption as a Function of Minute Ventilation

Oxygen consumption and minute ventilation data were obtained from the eight subjects who completed the current study. These data were collected during the levels determination session. The data were plotted and a regression equation fit to the data. The correlation coefficient, standard error ration of the model, standard error ratios of the coefficients, bias, and percentage prediction errors were calculated. The oxygen consumption residuals were plotted against minute ventilation.

Data from two subjects who started but did not complete the current study were used to validate the regression equation. The data were plotted with the regression line. Percentage errors were found.

Oxygen Consumption as a Function of Tidal Volume

Oxygen consumption and tidal volume data were obtained from the levels determination session of the current study. The data were plotted and a regression equation fit to the data. The following statistics were determined: correlation coefficient, standard error ratio of the model, standard error ratios of the coefficients, bias, mean bias, and percentage errors. The oxygen consumption residuals were plotted against the tidal volume.

Validation data were obtained from two subjects who started but did not complete the current study. Their data were plotted along the regression line. Percentage errors were obtained.

Actual Oxygen Consumption

Actual oxygen consumption was determined using the equation for oxygen consumption as a function of minute ventilation.

Oxygen Deficit

Oxygen deficit was found as the difference between required and actual oxygen consumption.

Performance Time

Performance time was found by dividing an estimate of the maximal oxygen deficit by the oxygen deficit.

Respiratory Rate and Respiratory Period

Respiratory rate was found by dividing the adjusted minute ventilation by the adjusted tidal volume. Respiratory period was determined from the inverse of the respiratory rate.

Exhalation Time as a Function of Respiratory Period

Data from the inhalation/exhalation study (Johnson et al., 2001) were used for this analysis. Subjects in this study exercised at 80-85% of V_{O2max} until voluntary termination while wearing one of nine combinations of inhalation and exhalation resistance. Subject files were combined so that one pooled data file was generated for each of the ten test conditions. Every third data point was extracted so that this data could be used for validation. Data from all conditions were then pooled. This resulted in a data set of 4396 pairs of data for the calibration and 2191 pairs of data for the validation.

A plot of exhalation time versus respiratory rate was obtained. A change of variable was made to linearize the equations and simplify the statistical analysis. The exponents in the power-law models that resulted from regression of exhalation time against respiratory rate were close to –1. Therefore, there should be a nearly linear relationship between exhalation time and the inverse of the respiratory rate. The inverse of the respiratory rate is the respiratory period. Therefore, exhalation times were plotted against respiratory period. A linear regression was obtained. The following statistics were determined: r, S_e/S_y, $S_e(b_0)/b_o$, $S_e(b_1)/b_1$, and model bias. The residuals were plotted against the respiratory period. Percent errors of the residuals were obtained.

The one-third of the data reserved for validation was plotted and a regression equation determined. A t-test was performed to determine if the slope and intercept of the regression on the validated data was the same as the slope and intercept of the regression on the calibration data set. For $n = \infty$, the critical t-value for $\alpha = 0.05$ for a two-tailed test was 1.96. The null hypothesis was that the slope (or intercept) coefficient from the validation data equaled the slope (or intercept) coefficient from the calibration data. The null hypothesis was accepted if the calculated t-value was less than 1.96 and greater than –1.96.

Breathing Waveform Based on Work Rate

Work rates at which the transitions between waveforms occur were estimated.

Respiratory Work Rate

Respiratory work rate equations were obtained from Johnson (1993). Inhalation and exhalation work rates were determined separately. The work of inhalation and exhalation was determined by multiplying the work rate by the corresponding time (inhalation or exhalation). The total respiratory work was found by adding the inhalation and exhalation work. Total respiratory work rate was calculated by dividing total respiratory work by the respiratory period.

Implementing and Evaluating the Model

The model was implemented in Visual BASIC. The program was structured so that future development of the model could be incorporated easily. Calculations were placed in functions so that the program was modular. Changes to the flow of the main section of the program would not affect those functions. Additional functions could be added easily.

Three stages of model evaluation were conducted. The first stage involved checking the accuracy of the calculations performed by the model. In the second stage, data from several subjects were used to evaluate the accuracy of the model. The third stage involved running simulations of the model at several work rates with and without a respirator and evaluating the results.

Model Equations

The programmed equations were checked to be sure they were entered correctly. By far the most complicated equations were the respiratory work equations developed by Johnson (1993). Values for minute ventilation and inhalation and exhalation times were provided in the paper for rest, and light, moderate, heavy, and very heavy exercise. Results of the work rate model were given for the individual work rate components for inhalation with sinusoidal, trapezoidal, and hybrid exponential waveforms during light exercise. Additionally, the total work rate of inhaling and exhaling with sinusoidal, trapezoidal, and hybrid exponential waveforms at rest and during light, moderate, heavy, and very heavy exercise were given. Data were given also for the individual work components for exhaling with the limited-flow hybrid exponential. The input values given in the paper were entered into the current model and the results compared to the results presented in Johnson (1993).

Other equations in the model were checked by calculator and by spreadsheet to ensure that mistakes had not been made either in entering the equations or in the logic that dictated their use.

Subject Simulations

Data from three subjects for the current study were used to evaluate the model output. One subject (224) completed stages one to five of the levels determination session and stages one to four of respirator condition A. The second subject (230) completed stages one to four of the levels determination session and stages one to three of respirator condition A. The third subject (002) participated in the current study. Data for this subject was rejected for two stages because the work rates were not in the targeted range. Data from one of the rejected stages was used here.

Additional data were obtained from three subjects who participated in an inhalation/exhalation resistance study (Johnson et al., 2001b). Nine combinations of resistances were used. The inhalation resistances (a, b, and c, respectively) were 1.84, 5.73, and 17.07 $cmH_2O/L/s$ while the exhalation resistances (d, e, and f, respectively) were 1.01, 1.69, and 4.75 $cmH_2O/L/s$. The subjects were not able to achieve a steady-state for all of the test conditions. Subject 145 reached a steady-state for all conditions except cf. Subject 214 attained a steady state for all conditions except af and cd. Finally, subject 216 reached a steady-state for all conditions except af, bd, ce, and cf.

The subject's weight and V_{O2max}, the treadmill speed and grade for the test, and the respirator characteristics were entered into the model and a simulation was run. Model simulation data were plotted against the measured value and a line of identity. These plots were obtained for oxygen consumption, minute ventilation, and tidal volume. The percentage errors were obtained.

Based on results from the three subjects who completed part of the current study, adjustments to the model were made. The Pandolf et al. (1977) equation was used to calculate physiological work rate. The relationship between physiological work rate and oxygen consumption was re-evaluated.

Oxygen consumption data from the eight subjects who completed the current study were used in the evaluation. Physiological work rates were calculated from the Pandolf et al. (1977) equation. The data were plotted and a linear regression performed. The following statistics were obtained: correlation coefficient, standard error ratio, bias, standard error of the coefficients.

Simulations were run again using the new methods. Calculated parameters were plotted against the associated measured parameters and a line of identity. Percentage errors were obtained. Results were compared to those obtained before the changes.

Mask / No Mask Simulations

Treadmill speeds and grades were determined for work rates in the ranges 25-30%, 35-40%, 45-50%, 65-70%, and 80-85%. These work rates were chosen to correspond to the work rates in the current study. An additional simulation was run at an external work rate of zero achieved by setting the treadmill speed and grade to zero. The U.S. Army M40 respirator was selected for the mask simulations. Other than changing the mask and the treadmill speed and grade, all other inputs remained at their default values.

The program was run at rest and the five work rates for the no mask and mask conditions. Output files were generated for each simulation. Plots of adjusted minute ventilation, adjusted tidal volume, adjusted oxygen consumption, respiratory rate, inhalation time, exhalation time, inhalation work rate, exhalation work rate, inhalation work, exhalation work, total respiratory work, and total respiratory work rate versus percent of maximal oxygen consumption were obtained. The $\%V_{O2max}$ was based on the required oxygen consumption instead of the oxygen consumption adjusted for respirator mask resistance and dead volume so that direct comparisons between the mask and no mask conditions could be made.

RESULTS AND DISCUSSION

The model was developed in four stages. During the first stage, the model structure was selected. Experimental data were obtained during stage two. The third stage involved selecting and developing equations for the model. The model was implemented in Visual BASIC and tested.

Structure of the Model

The structure of the model is shown in Figure 1. The aim of the current model was to predict the effects of a respiratory protective mask on a person during physical activity. Resistive loads have a number of effects on respiration. Respiratory rate decreases and inhalation and exhalation times increase (Johnson, 1991). Minute ventilation and oxygen consumption decrease (Johnson et al., 1999; Caretti et al., 2001; Flook and Kelman, 1973; Hermansen et al., 1972; Silverman et al., 1951). Other effects are important as well. Tidal volume may increase due to the dead volume of the respirator (Stannard and Russ, 1948). Respiratory work increases with increases in work rate and with the addition of a respirator (Johnson, 1991; Johnson, 1992). The decreased oxygen consumption would indicate that an oxygen deficit existed.

As the current model will form the framework for future modeling efforts to predict the performance time of respirator wearers during physical activity, oxygen

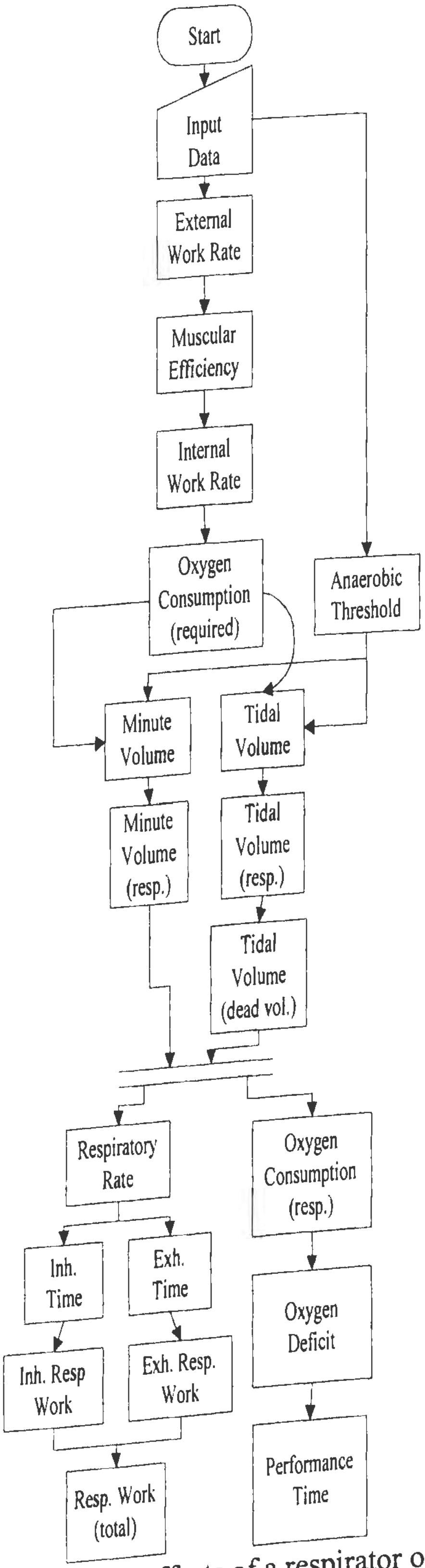

Figure 1. Flowchart of the model of the effects of a respirator on the pulmonary system during physical activity.

deficit would be an important factor to consider. An estimate of performance time could be made by dividing the maximum oxygen deficit by the oxygen deficit of the activity. This might not provide a very accurate indicator of performance time, but would provide the structure for future development of the model.

While it was not necessary to calculate respiratory work to determine the effects of the respirator on breathing parameters such as oxygen consumption and minute ventilation, it was felt that the addition of respiratory work calculations would aid in the understanding of the effects of the respirator on pulmonary function.

The outputs of the model were chosen to be oxygen consumption, minute ventilation, tidal volume, oxygen deficit, performance time, respiratory rate, inhalation and exhalation times, and respiratory work. In order to determine these parameters, a number of inputs were required. The output parameters were affected by the external work rate, subject characteristics, respirator characteristics, and respiratory system characteristics. The subject characteristics were age, height, weight, and maximal oxygen consumption. Respirator characteristics included inhalation and exhalation resistances, mass, and dead volume. Respiratory system characteristics included additional dead volume and resistance. Parameters of the model may be affected also by race/national origin, anxiety level, drugs, circulating hormones, and body temperature.

Physical activity begins at a certain external work rate. There is an efficiency associated with that work rate and the activity being performed. An amount of physiological work must be done by the body to generate the external work. The amount of oxygen required by the body is dependent on the physiological work rate.

From the oxygen consumption, minute ventilation and tidal volume can be determined. Respiration rate is found by dividing minute ventilation by tidal volume. Inhalation and exhalation times can be found from the respiration rate. Respiratory work rate depends on minute ventilation and inhalation and exhalation times. When a respirator is worn, the minute ventilation, tidal volume, and oxygen consumption are altered. An oxygen deficit results and performance time is affected. This process led to the model structure shown in Figure 1.

Experimental Testing

Experimental testing was conducted in order to obtain data for stage three, the development of equations for the model. Sufficient data were not found in the literature to develop equations to determine the effects of respirator resistance on minute ventilation, tidal volume, and oxygen consumption during work between 25 and 80% of maximal oxygen consumption.

Subject Demographics

Subjects who participated in any study in the Human Performance Lab were assigned a subject number. Subjects who had completed testing previously retained the same subject number. So, subject 023 was the twenty-third subject tested in the lab under the current numbering system. Therefore, non-consecutive subject numbers did not indicate missing data, but instead indicated the order in which the subjects started testing in the lab. Subject information for the eight subjects in the current study is shown in Table 3. Subjects 224 and 230 could not complete all the testing sessions; their data were not included.

Table 3. Demographic information for the eight subjects in the current study.

Subject	Height (cm)	Mass (kg)	Age (years)	Gender	V_{O2max} (L/min)	V_{O2max} (ml/kg/min)	AT (%)	STAI Trait
001	172	95	38	M	4.42	48.4	92	28
002	160	58	34	F	2.38	41.0	78	46
023	163	47	31	F	2.06	43.8	76	48
145	175	92	30	M	3.53	38.4	80	44
173	183	75	29	M	3.17	42.3	85	21
214	178	77	20	M	4.97	64.5	64	38
221	178	75	23	M	4.7	62. 7	68	35
231	171	61.7	23	F	2.56	41.5	70	41
Mean	172.5	72.2	28.5		3.47	47.8	77	37.6
S.D.	7.8	15.9	6.1		1.12	10.1	9	9.3

The anaerobic thresholds given in Table 3 are generally higher than expected (Weltman et al., 1978). The subjects were generally fit although only subject 001 was actively training. The other subjects participated in recreational sports usually involving hiking, biking, and jogging two to three times per week.

Determining Steady-State Minute Ventilation and Tidal Volume

The work intensity expressed as percentage of V_{O2max} at each of the five stages is presented in Table 4 for each of the eight subjects.

Table 4. Work intensities for each of the eight subjects in the current study expressed as %VO2max. The targeted ranges for the five stages were: 25-30%, 35-40%, 45-50%, 65-70%, and 80-85%.

Subject	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
001		39.5%	48.3%	69.2%	83.3%
002	21.4%	30.25%	43.9%	60.1%	72.2%
023	28.6%	37.3%	52.2%	70.3%	81.1%
145	29.0%	35.3%	45.6%	62.2%	82.3%
173	30.2%	38.9%	49.3%	70.7%	82.2%
214	29.9%	38.1%	45.0%	68.2%	79.1%
221	23.9%	38.2%	45.7%	70.5%	82.1%
231	26.0%	38.5%	47.3%	69.6%	86.1%

For subject 002, the work rates for stages 1, 2, 4, and 5 were not in the targeted range. The stage two data was moved to stage one, while the stage 5 data was moved to stage 4. There was then missing data for stages two and five. Subject 001 had a hard time maintaining constant breathing during stage one; a steady-state value was not determined.

Evaluation of Oxygen Drift and Subject Variability

In subject 145's first respirator session the subject performed stages one to five without a break. Because of concerns of the possibility of oxygen drift occurring at the higher work rates, the test was repeated twice with the subject getting break periods and returning to resting oxygen consumption levels before starting the next stage. (See Appendix B, Figures 64 to 66)

A regression line was fit to the last four minutes of data from stage five for each of the three tests (see Appendix B, Figures 67 to 69). None of the slopes was statistically significantly different from zero at the $\alpha = 0.05$ level. In fact, the probability levels for the three tests were 0.19, 0.30, and 0.46. Thus, oxygen drift was not occurring during the testing.

Only stage five was evaluated because at that stage the given subject was slightly above the anaerobic threshold. The slow component of oxygen consumption as defined by Poole and Richardson (1997) only occurs above the anaerobic threshold. These authors stated that the onset of the slow component occurred 80 to 100 seconds after the start of exercise in this domain. While other researchers such as

Kearon et al. (1991) have found increases in oxygen consumption at work rates below the anaerobic threshold, these increases were more likely due to oxygen drift rather than the slow component of oxygen consumption because the sessions lasted for sixty minutes.

The steady-state values determined from the short stages in the current study corresponded to the initial steady state in the two-exponential transient response of oxygen consumption reported by Barstow and Mole (1991). This was the steady state for the fast component of the oxygen response.

The rest periods between stages were instituted because of the results of Kearon et al. (1991). Although oxygen drift was not detected, subjects in later tests completed stages one to three and then took a break until oxygen consumption returned to resting values. Stage four was completed and then the subject took a break and returned to baseline before completing stage five.

The variability in the oxygen consumption response was evaluated also from the three repeated tests. The average oxygen consumptions for the five stages are shown in Table 5.

Table 5. Oxygen consumption values (L/min) for subject 145 during three repeated tests of the standard respirator condition. Percentage differences between the first and second, first and third, and second and third tests are presented in the last three columns.

Stage	Test 1	Test 2	Test 3	1 to 2	1 to 3	2 to 3
1	1.04	1.17	1.14	12.7	10.3	-2.1
2	1.23	1.36	1.32	10.6	7.1	-3.2
3	1.80	1.89	1.82	1.8	0.8	-3.8
4	2.7	2.69	2.56	-0.2	-5.4	-5.1
5	3.59	3.53	3.33	-1.6	-7.4	-5.9

Slightly larger differences occur at the lower work rates. This is not unexpected; changes in gait and arm movements at low work rates affect oxygen consumption more than at high work rates. The variability between tests was evaluated to determine the amount of variability that might be expected in a person's performance. This subject did not have much variability between test sessions.

Steady-State Values

Four respirator conditions were evaluated. The first was the half-mask used during the test to determine treadmill speed and grade for each stage. This test session will hereafter be referred to as the levels determination session. The inhalation and exhalation resistance were 0.7 and 0.8 $cmH_2O/L/s$, respectively. The dead volume of the mask was approximately 125 mL. Respirators A, B, and C had inhalation and exhalation resistances of 0.88 and 1.69, 1.84 and 1.69, and 5.73 and 1.01 $cmH_2O/L/s$. The approximate dead volume of each of these three respirators was 300 mL. The average steady-state minute ventilation and tidal volume values for each respirator condition are shown in Tables 6 and 7.

Table 6. Steady state minute ventilation (L/s) for stages one to five for each of the three respirator conditions. Values reported are means ± one standard deviation.

Stage	Half-Mask	Respirator A	Respirator B	Respirator C
1	0.35 ± 0.11	0.33 ± 0.09	0.33 ± 0.08	0.33 ± 0.08
2	0.46 ± 0.12	0.44 ± 0.12	0.44 ± 0.11	0.44 ± 0.11
3	0.57 ± 0.17	0.53 ± 0.16	0.51 ± 0.15	0.53 ± 0.14
4	0.89 ± 0.27	0.83 ± 0.28	0.79 ± 0.23	0.80 ± 0.22
5	1.28 ± 0.46	1.22 ± 0.45	1.12 ± 0.36	1.05 ± 0.28

Table 7. Steady state tidal volume (L) for stages one to five for each of the three respirator conditions. Values reported are means ± one standard deviation.

Stage	Half-Mask	Respirator A	Respirator B	Respirator C
1	0.59 ± 0.24	0.72 ± 0.26	0.66 ± 0.22	0.65 ± 0.21
2	0.80 ± 0.28	1.00 ± 0.38	0.98 ± 0.37	0.89 ± 0.27
3	1.03 ± 0.40	1.15 ± 0.47	1.06 ± 0.37	1.02 ± 0.35
4	1.47 ± 0.55	1.50 ± 0.52	1.48 ± 0.43	1.46 ± 0.43
5	1.84 ± 0.57	1.91 ± 0.64	1.89 ± 0.58	1.78 ± 0.34

Development of Equations

During this stage, equations were determined to fill in the model structure. Existing equations were used if they were available. If not, new equations were developed. A summary of the equations used in the model is shown in Table 8. Units for the equations and descriptions of the variables are found within the text.

Table 8. Summary of the equations used in the model. See the text for explanations of the variables and the units. Numbers refer to equations within the text.

External Work Rate

$$WR_{ext} = \frac{\text{cadence} \cdot \text{load} \cdot \dfrac{\text{distance}}{\text{revolution}} \cdot g}{60} \qquad (3)$$

$$WR_{ext} = h_{step} \cdot \text{mass} \cdot n_{step} \cdot g \qquad (4)$$

$$WR_{ext} = m_t \cdot g \cdot v \cdot \frac{G}{100} \qquad (6)$$

Efficiency as a Function of Work Rate

$$\eta = \frac{WR_{ext}}{200} \qquad 0 \le WR_{ext} < 20.1 \qquad (48)$$

$$\eta = 0.1003 + 0.0006(WR_{ext} - 20.1) \qquad 20.1 \le WR_{ext} < 159.3 \qquad (49)$$

$$\eta = 0.183 + 0.0002(WR_{ext} - 159.3) \qquad 159.3 \le WR_{ext} < 240 \qquad (50)$$

$$\eta = 0.2 \qquad 240 \le WR_{ext} \qquad (51)$$

Physiological Work Rate

$$WR_{phys} = \frac{WR_{ext}}{\eta} \qquad (52)$$

Oxygen Consumption as a Function of Physiological Work Rate

$$V_{O2} = 0.002952 WR_{phys} \qquad (55)$$

Anaerobic Threshold as a Function of Maximal Oxygen Consumption

$$AT = 0.8624 V_{O2max} - 7.1585 \qquad (58)$$

Minute Ventilation as a Function of Oxygen Consumption

$$\%V_{E\max} = 0.0095 \cdot \%V^2_{O2\max} - 0.133 \cdot \%V_{O2\max} + 17.153 \qquad (69)$$

$$V_{Emax} = 20.01 V_{O2max} + 27.855 \qquad (70)$$

Tidal Volume as a Function of Oxygen Consumption

$$\%V_{Tmax} = 0.9987 \cdot \%V_{O2max} - 1.6809 \qquad (72)$$

$$V_{Tmax} = 0.3864 \cdot V_{O2max} + 0.6416 \qquad (73)$$

Change in Minute Ventilation with Resistance

$$25\text{-}30\%\ V_{O2max}: \quad V_E = 0.3705 - 0.0037R_{inh} - 0.02236R_{exh} \tag{75}$$

$$35\text{-}40\%\ V_{O2max}: \quad V_E = 0.4754 - 0.0018R_{inh} - 0.0206R_{exh} \tag{76}$$

$$45\text{-}50\%\ V_{O2max}: \quad V_E = 0.6088 - 0.0065R_{inh} - 0.0469R_{exh} \tag{77}$$

$$65\text{-}70\%\ V_{O2max}: \quad V_E = 0.9718 - 0.0156R_{inh} - 0.0846R_{exh} \tag{78}$$

$$80\text{-}85\%\ V_{O2max}: \quad V_E = 1.3979 - 0.0454R_{inh} - 0.0967R_{exh} \tag{79}$$

Change in Tidal Volume with Resistance

$$25\text{-}30\%\ V_{O2max}: \quad V_T = 0.5023 + 0.0059R_{inh} + 0.1046R_{exh} \tag{80}$$

$$35\text{-}40\%\ V_{O2max}: \quad V_T = 0.6271 + 0.0092R_{inh} + 0.2080R_{exh} \tag{81}$$

$$45\text{-}50\%\ V_{O2max}: \quad V_T = 0.9698 - 0.0091R_{inh} + 0.0890R_{exh} \tag{82}$$

$$65\text{-}70\%\ V_{O2max}: \quad V_T = 1.4525 - 0.0027R_{inh} - 0.0024R_{exh} \tag{83}$$

$$80\text{-}85\%\ V_{O2max}: \quad V_T = 1.7955 - 0.0162R_{inh} + 0.0746R_{exh} \tag{84}$$

Change in Minute Ventilation with Dead Volume

$$\Delta V_E = 0.170432V_D - 0.00681 - \frac{(\%V_{O2max} - 0.15)}{0.15} \cdot \left(\frac{1.8}{60}\right) \tag{87}$$

Change in Tidal Volume with Dead Volume

$$\Delta V_T = 0.1950 + 0.2517V_D - \frac{0.4256\%V_{O2max}}{100} \tag{90}$$

Oxygen Consumption as a Function of Resistance and Dead Volume

$$V_{O2} = 0.0340V_E + 0.4322 \tag{91}$$

Oxygen Deficit

$$O_2\ \text{deficit} = V_{O2,required} - V_{O2,adjusted} \tag{93}$$

Performance Time

$$\text{Perf time} = \left(\frac{4.03}{O_2 \text{ deficit}} \right) \tag{94}$$

Respiratory Rate

$$RR = \frac{V_{E,\text{adjusted}}}{V_{T,\text{adjusted}}} \tag{95}$$

Respiratory Period

$$RPD = \frac{1}{RR} \tag{96}$$

Exhalation Time as a Function of Respiratory Period

$$T_{exh} = 0.6176RPD - 0.2145 \tag{97}$$

External Work Rate

Equations for determining external work rate for walking or running, stepping, and cycling were discussed previously. Equations 3, 4, and 6 were selected for cycling, stepping, and walking, respectively. These equations were:

$$WR_{ext} = \frac{\text{cadence} \cdot \text{load} \cdot \dfrac{\text{distance}}{\text{revolution}} \cdot g}{60} \tag{3}$$

$$WR_{ext} = \text{h}_{\text{step}} \cdot \text{mass} \cdot \text{n}_{\text{step}} \cdot \text{g} \tag{4}$$

$$WR_{\text{ext}} = \text{m}_{\text{t}} \cdot g \cdot \text{v} \cdot \frac{\text{G}}{100} \tag{6}$$

Efficiency as a Function of External Work Rate

A series of four equations (equations 9 – 12) were developed by Johnson (1992) that related gross efficiency to external work rate. Equations were developed for ranges of 0 to 10 W, 10 to 140 W, 140 to 240 W, and 240 W or greater. Data from the literature were used to assess these equations. If an equation for one, or more, of the ranges did not fit well, a new equation was developed for that region or regions.

A plot of the data and the Johnson (1992) equation is shown in Figure 2. Data were taken only from studies that used direct calorimetry because indirect calorimetry was used in a later part of the model. Using indirect calorimetry to fit the curve for efficiency would preclude its use in fitting curves in the latter part of the model as

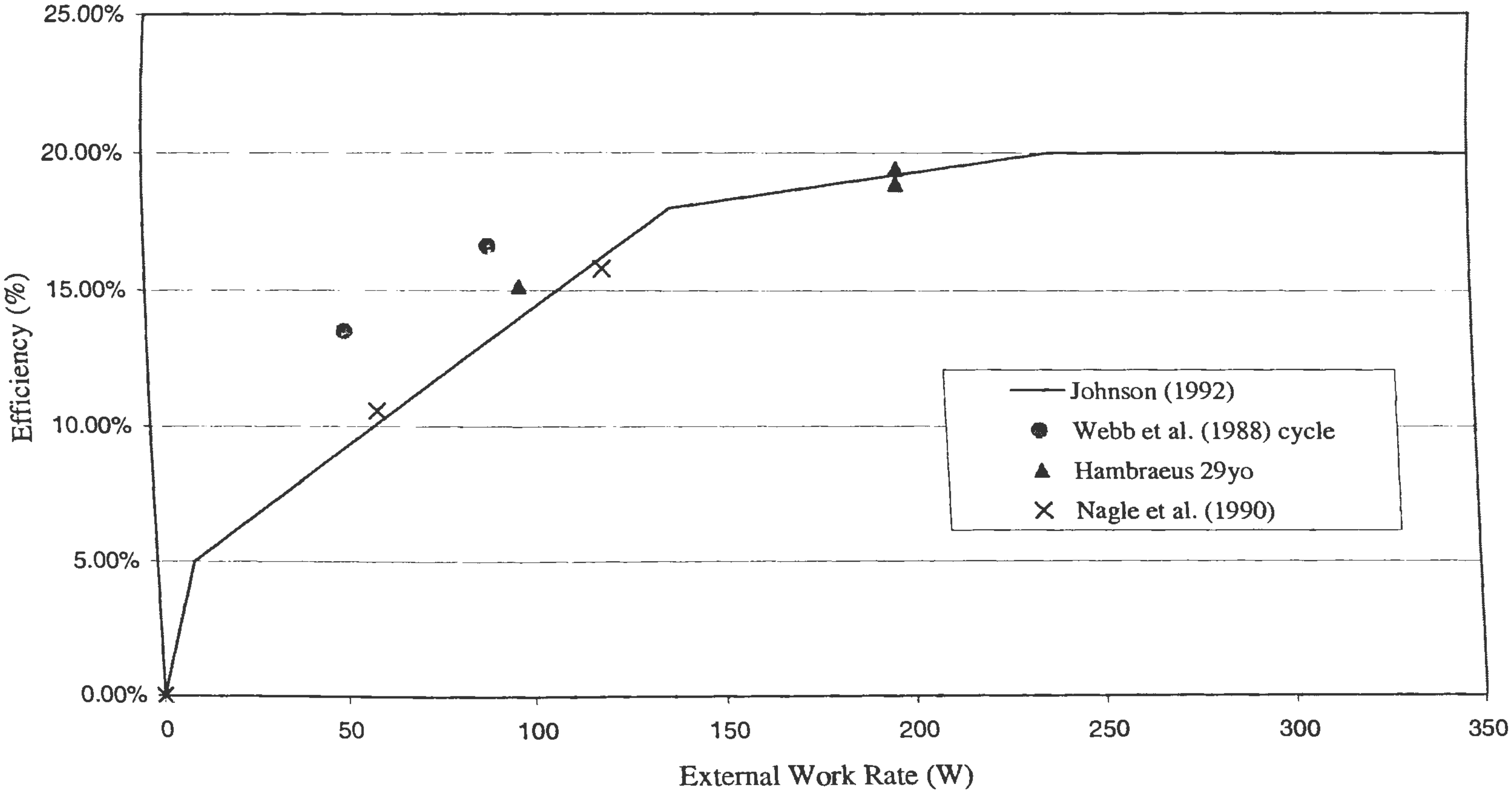

Figure 2. Efficiencies from three studies plotted against external work rate and the equations developed by Johnson (1992).

parameters in latter parts of the model will be based on values from the efficiency equation. Only one data point was available in the region from 0 to 10W and this was for 0W where efficiency is 0%. No direct calorimetry points were available for work rates greater than 240W. In the 140-240 W range, there were two data points. The percent errors of these two points were –1.12 and 1.76%. While the errors were small, both data points were obtained from one subject at the same work rate of 200W. So, the equation fits well for this one subject, but not much else can be said about the equation.

In the 10 – 140 W range, there were five data points. The percent errors for these points were 30, 21, 7.6, 4.5, and -2.5%. So, for four of the five data points the equation over-predicts the efficiency. The bias of the model in this region was 0.09 while the mean bias (bias divided by y-mean) was 0.61. Both of these criteria indicated that the model was biased. Again, with so few data points, not too much can be said about the fit of the equation. If more data were available, it is possible that due to the variability of physiological data, the equation may actually under-predict. However, using the only data available, it seemed that the equation for the 10 to 140 W range (equation 10) should be changed.

The five data points that were in the 10 to 140 W region and the linear regression line fit to these data are shown in Figure 3. The equation was:

$$\eta = 0.0006 \cdot WR_{ext} + 0.0883 \qquad (47)$$

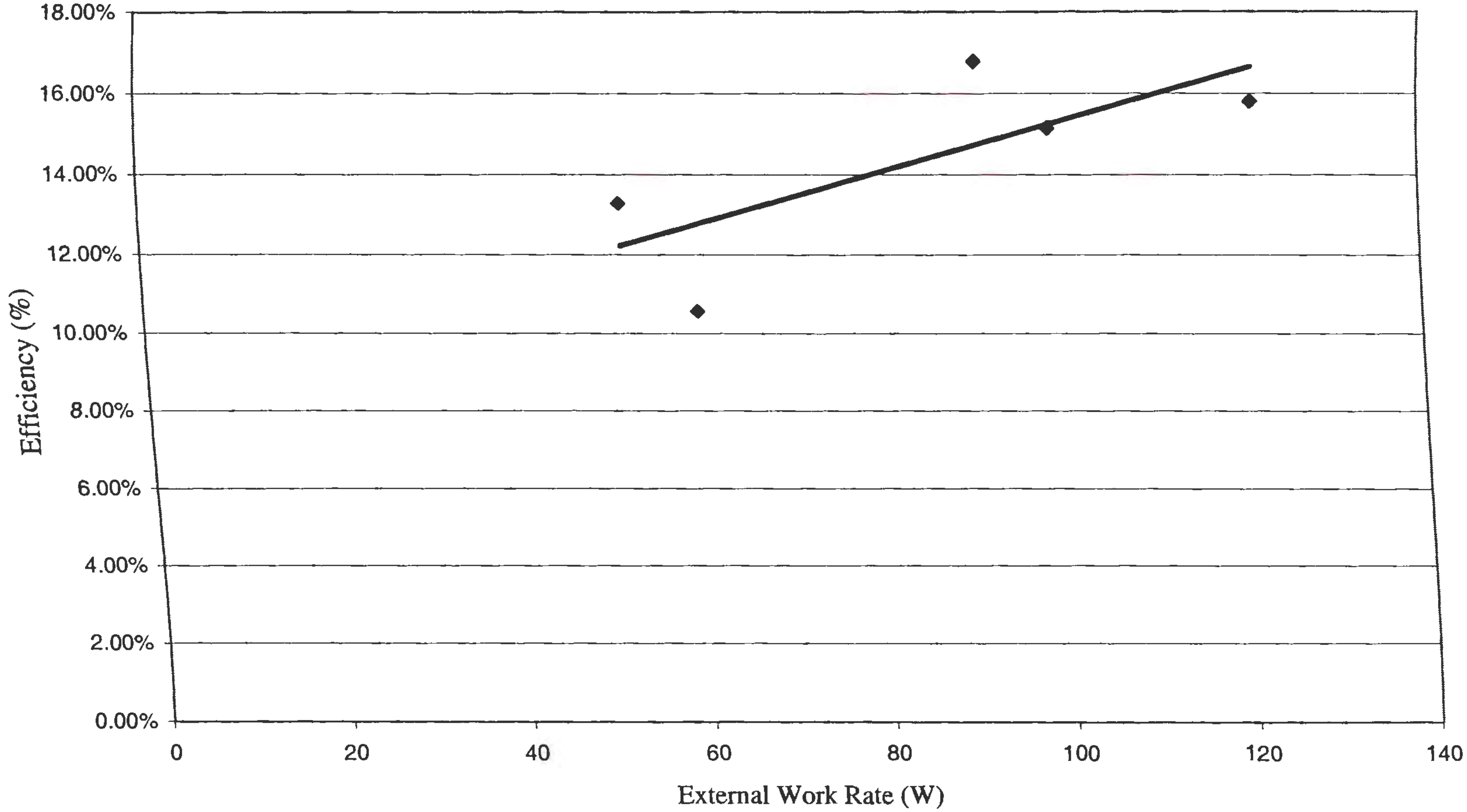

Figure 3. Best fit line through efficiencies for work rates of 10 - 140 W.

A plot of equation 47 with the equations for the other regions is shown in Figure 4. The intersections of equation 47 with the equations of the two adjacent regions were found. The intersection between equation 47 and the equation for the range 140 to 240 W was 159.3 W, the upper bound for equation 47. The lower bound of the region for equation 47 was 20.1 W. The resulting equations for efficiency versus external work rate were:

$$\eta = \frac{WR_{ext}}{200} \qquad 0 \le WR_{ext} < 20.1 \qquad (48)$$

$$\eta = 0.1003 + 0.0006(WR_{ext} - 20.1) \qquad 20.1 \le WR_{ext} < 159.3 \qquad (49)$$

$$\eta = 0.183 + 0.0002(WR_{ext} - 159.3) \qquad 159.3 \le WR_{ext} < 240 \qquad (50)$$

$$\eta = 0.2 \qquad 240 \le WR_{ext} \qquad (51)$$

The plot of equations 48-51 and the data are shown in Figure 5. The errors for the five points in the region 20.1 to 159.3 W were 9.6, 14.5, 2.1, -18.1 and -2.2%. The bias of the model for this region was reduced from 0.090 to 0.018 while the mean bias was reduced from 0.61 to 0.12. The fact that the bias was still negative indicated that the model continued to over-predict the efficiency in the range. However, the bias and mean bias were decreased by 80%. Thus, equation 49 fit the data more accurately than did equation 10.

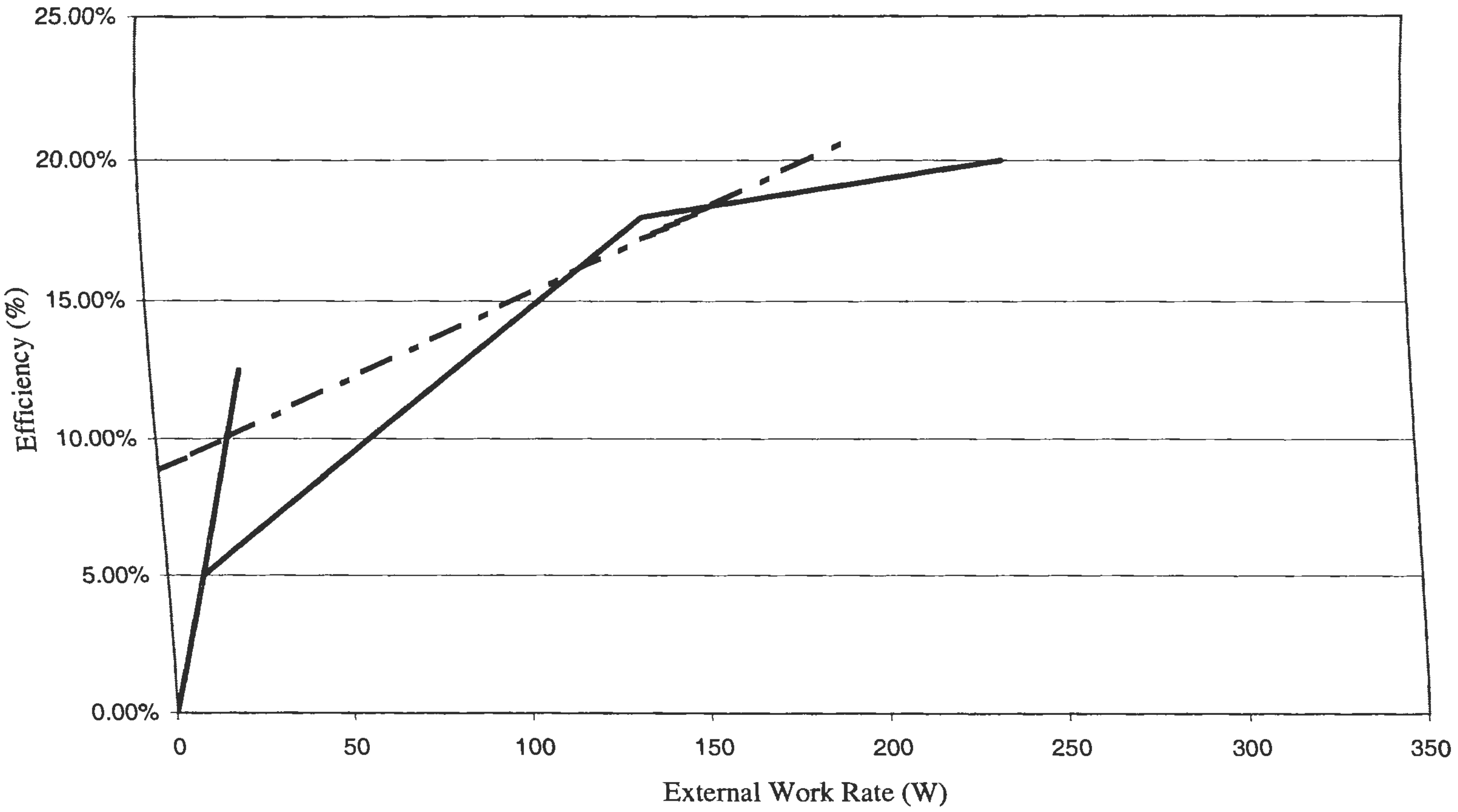

Figure 4. Intersection of the new regression line through the Johnson (1992) equations.

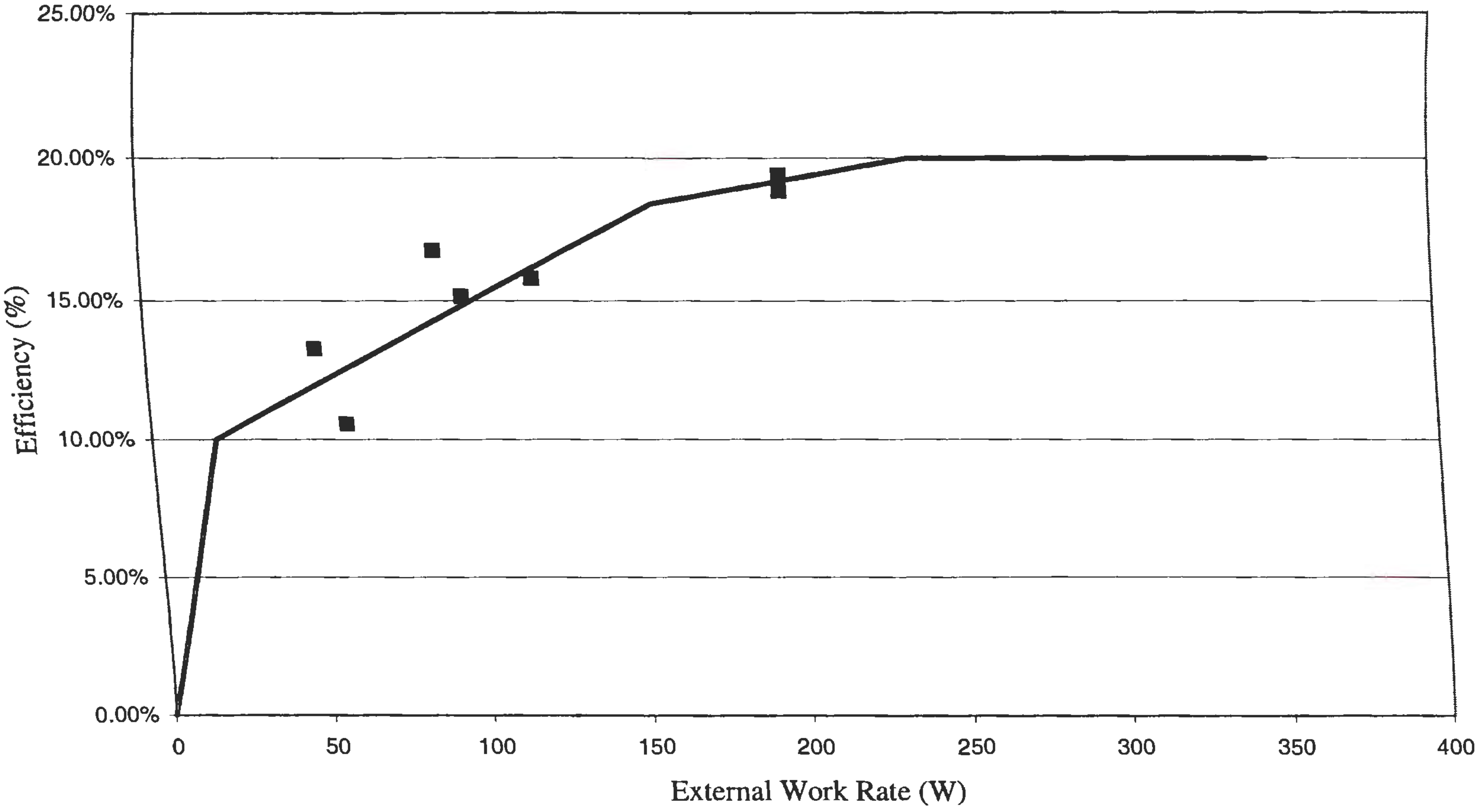

Figure 5. Data plotted against the new set of efficiency equations.

The study conducted by Johnson et al. (2001a) showed that the efficiency of negative work was equal to –2 times the efficiency for positive work. Therefore, negative efficiency was obtained by multiplying by –2 the efficiency for positive external work rate determined from the Johnson (1992) equations. A plot of the Johnson (1992) equations and two negative efficiency data points are shown in Figure 6. Both the negative efficiency and work rate are plotted as positive values. The percent errors for these two points were -1 and 33.6%. The Johnson (1992) equation under-predicted the efficiency.

A plot of the two negative efficiencies with the new equation is shown in Figure 7. The errors for the two points were 25 and –34%. The bias was decreased from –0.16 to –0.12 while the mean bias was reduced from –0.47 to –0.34. So, the equation still had a bias, but it was smaller.

Further statistical analysis with such a small data sample was not warranted. However, efficiencies from two studies (Luhtanen et al., 1987; Gaesser and Brooks, 1975) that calculated internal work rate were used to evaluate the fit. The data are plotted with equations 48-51 in Figure 8. The two studies were not used in calibrating the model because the calculated internal work rates were used later in the development of the model. The percent errors for the Luhtanen et al. (1987) data ranged from –15 to 11%. The ranges of percent errors from the Gaesser and Brooks (1975) data for 40, 60, 80, and 100 rpm were 10 to 25%, 11 to 23%, -6 to 16%, and -42 to 3%, respectively. So, the equations seemed to provide reasonable predictions

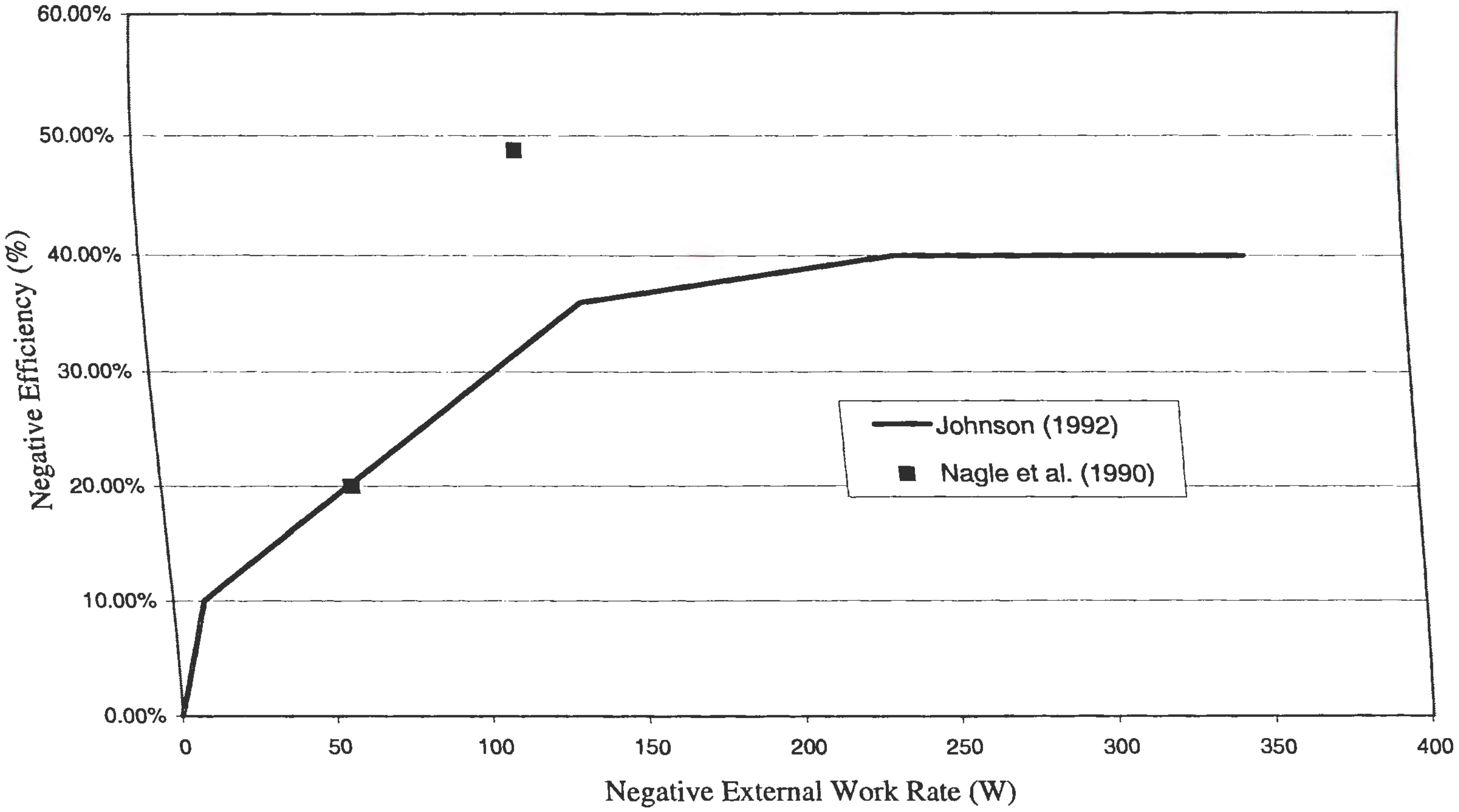

Figure 6. Negative efficiencies plotted with the Johnson (1992) regression lines.

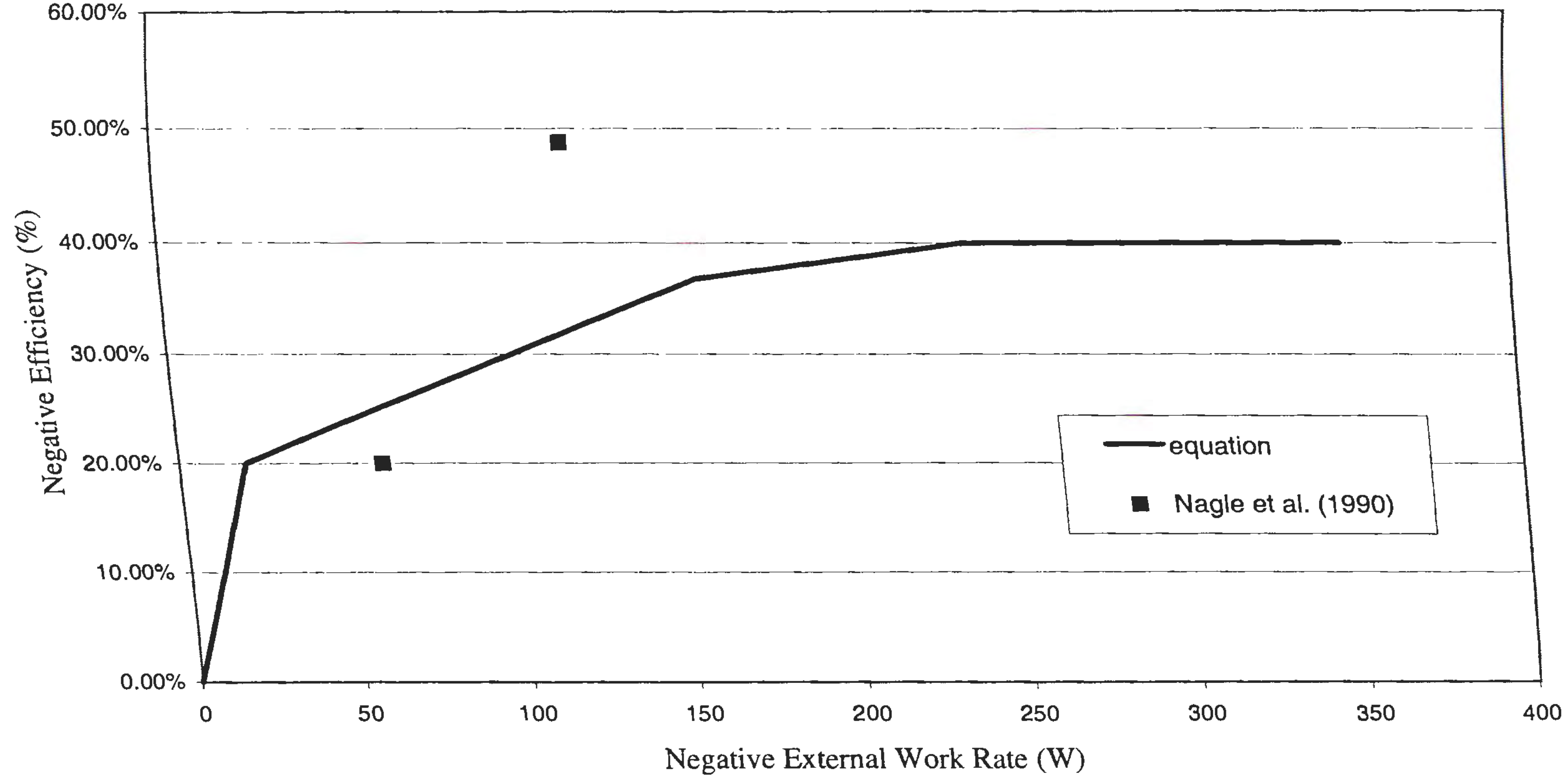

Figure 7. Negative efficiencies plotted with the new regression lines.

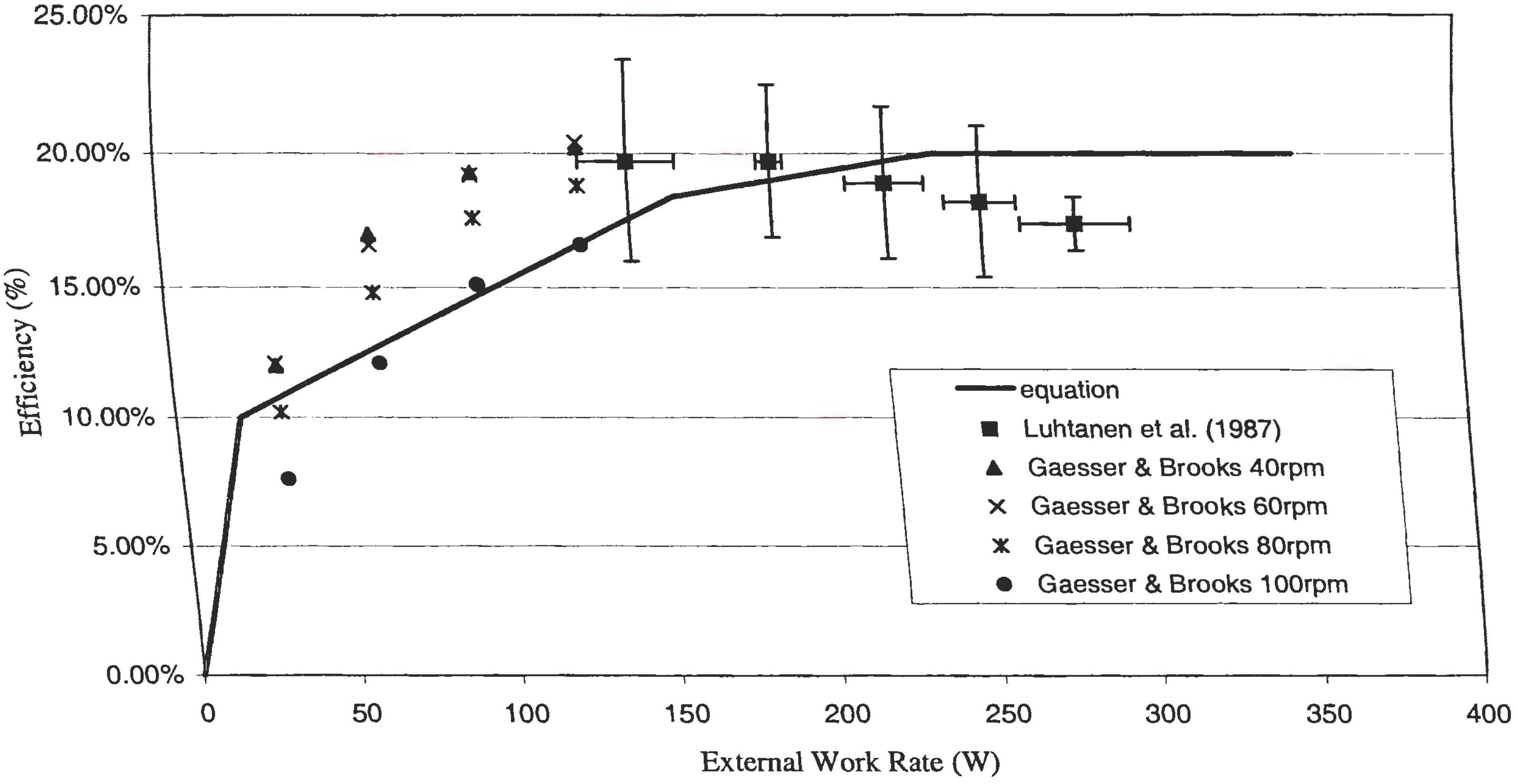

Figure 8. Efficiency data from the literature plotted with the new regression lines.

of efficiency based on external work rate when looking at a limited number of data points.

Physiological Work Rate

Physiological work rate was found by dividing the external work rate by the efficiency:

$$WR_{phys} = \frac{WR_{ext}}{\eta} \tag{52}$$

where: WR_{phys}, physiological work rate, W

If the external work rate is zero, the model assumes zero efficiency, and a physiological work rate equal to the basal metabolic rate. However, if the person is running on level ground, the person has a physiological work rate much higher than basal metabolic rate. For these cases, the physiological work rate was calculated. Pandolf et al. (1977) provided an equation for determining physiological work rate for subjects who were walking or standing with or without loads on different types of terrain. The authors and other independent researchers (Myles and Saunders, 1979) found good agreement between predicted and measured values. The equation was:

$$\begin{aligned} WR_{phys} &= 0.15W_b + 0.20(W_b + W_l)(W_b/W_l)^2 \\ &+0.102\zeta(W_b + W_l)(1.5v^2 + 35vG/100) - (W_b + W_l)vG/100 \end{aligned} \tag{53}$$

where: W_b, body weight, N

W_l, total load weight, N

ζ, terrain coefficient, dimensionless

Terrain coefficients varied from 1.0 for treadmill or blacktop surfaces to 2.1 for loose sand.

Oxygen Consumption

Originally, the intent was to substitute the Johnson (1992) equations relating respiratory exchange ratio to oxygen consumption and V_{O2max} into the Lusk (1928) equation relating physiological work rate to respiratory exchange ratio and oxygen consumption. The Johnson (1992) equations specified three equations for RER. The selected equation depended on the $\%V_{O2max}$. Thus, the oxygen consumption must be known to determine which equation to use. The three quadratic equations could be solved for the oxygen consumption based on the physiological work rate, V_{O2max}, and $\%V_{O2max}$. The problem was that in order to determine $\%V_{O2max}$, the oxygen consumption was needed. Another way to determine the oxygen consumption was needed.

Astrand and Rodahl (1970) showed that the oxygen consumption was a linear function of the physiological work rate (their Figure 13-2). Based on that figure, a regression was performed relating oxygen consumption to physiological work rate (see Appendix B, Figure 70). The regression equation was:

$$V_{O2} = 0.002977 WR_{phys} - 0.01748 \qquad (54)$$

where: V_{O2}, oxygen consumption, L/min

WR_{phys}, physiological work rate, W

The correlation coefficient was 0.994. The standard error ratio was 0.109, indicating that equation 54 provided better predictions than predictions made with the mean. The bias and mean bias were zero. The results of the t-test indicated that the slope coefficient was significantly different from zero, but that the intercept coefficient was not significantly different from zero. Because the intercept was not different from zero, a zero-intercept model was used.

The zero-intercept regression equation was:

$$V_{O2} = 0.002952 WR_{phys} \qquad (55)$$

A plot of the data and regression line is shown in Figure 9. The correlation coefficient was 0.994. The standard error ratio was 0.11. If the S_e is less than S_y, then the model makes better predictions of the y-variable than the mean. If the standard error ratio, S_e/S_y, is close to zero, a significant improvement in prediction accuracy has occurred. Thus, predictions made with equation 55 were better than predictions made with the mean. The bias was –0.07 and the mean bias was –0.03. Thus, the model tends to under-predict. The adjusted correlation coefficient was

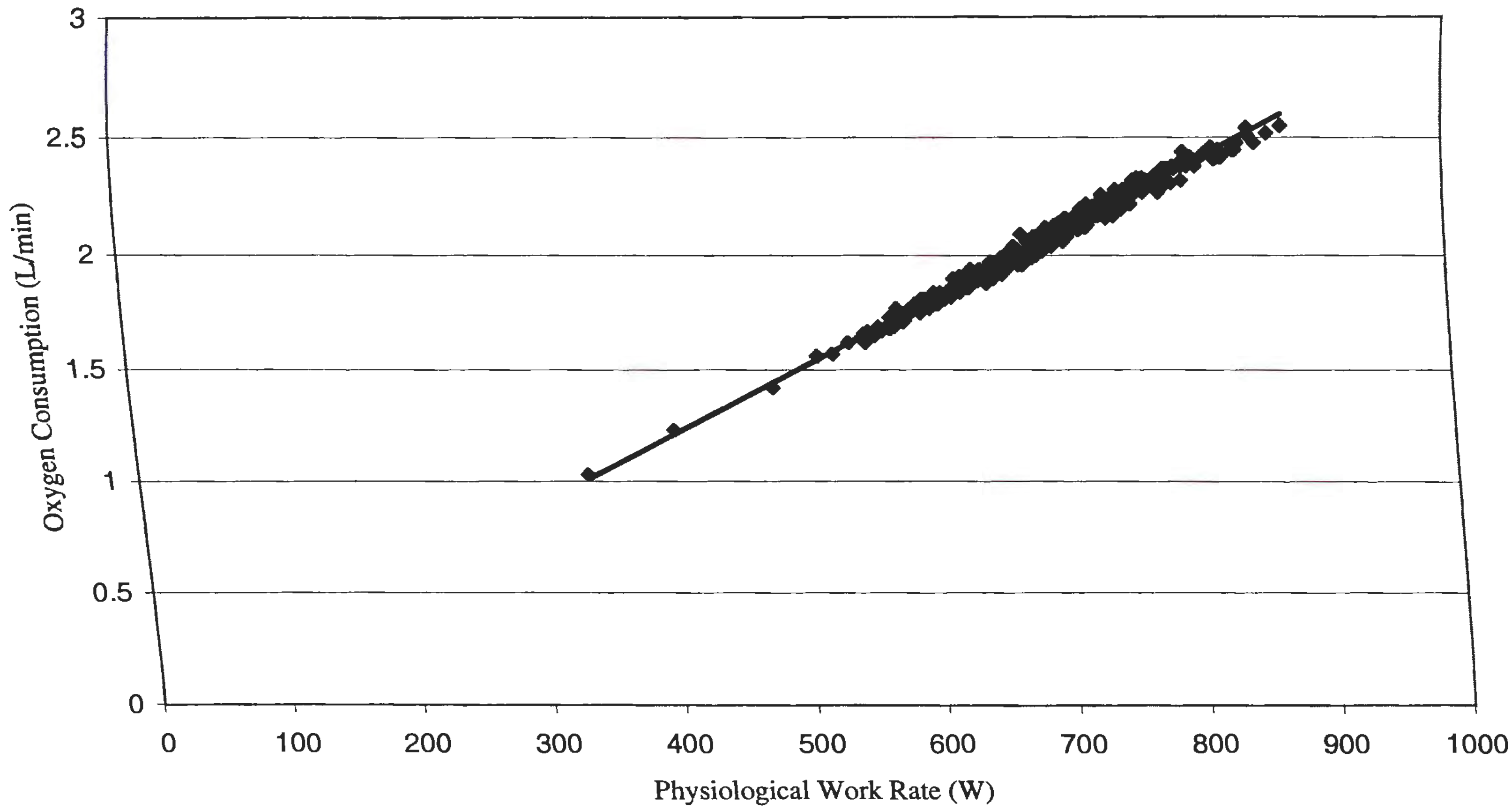

Figure 9. Calibration data and the zero-intercept regression line.

0.985. The standard correlation coefficient assumes a model with a zero bias. The adjusted correlation coefficient is a more accurate measure of the model's goodness of fit if there is a bias. A correlation coefficient (standard or adjusted) of one indicates a perfect fit. So, the adjusted correlation coefficient indicated that there was a high degree of fit even though there was a small bias.

The partial regression coefficient was 0.986. Values close to one indicate an important predictor. The standard error of the coefficient was 0, indicating that the slope coefficient was an important predictor. From the plot of the residuals it appears that the error became larger as physiological work rate increased (see Appendix B, Figure 71). The percentage errors were between –1.9% and 4.6%. So, overall, equation 55 provided accurate predictions of oxygen consumption based on physiological work rate.

The zero-intercept model fit to the validation data was:

$$V_{O2} = 0.002947WR_{phys} \tag{56}$$

A plot of the data and the regression line are shown in Figure 10. The correlation coefficient was 0.9949. The calculated t-value was –0.024. As this value was less than ± 1.976, the critical t-value, the null hypothesis was accepted. That is, the slopes of the calibration and validation equation were the same.

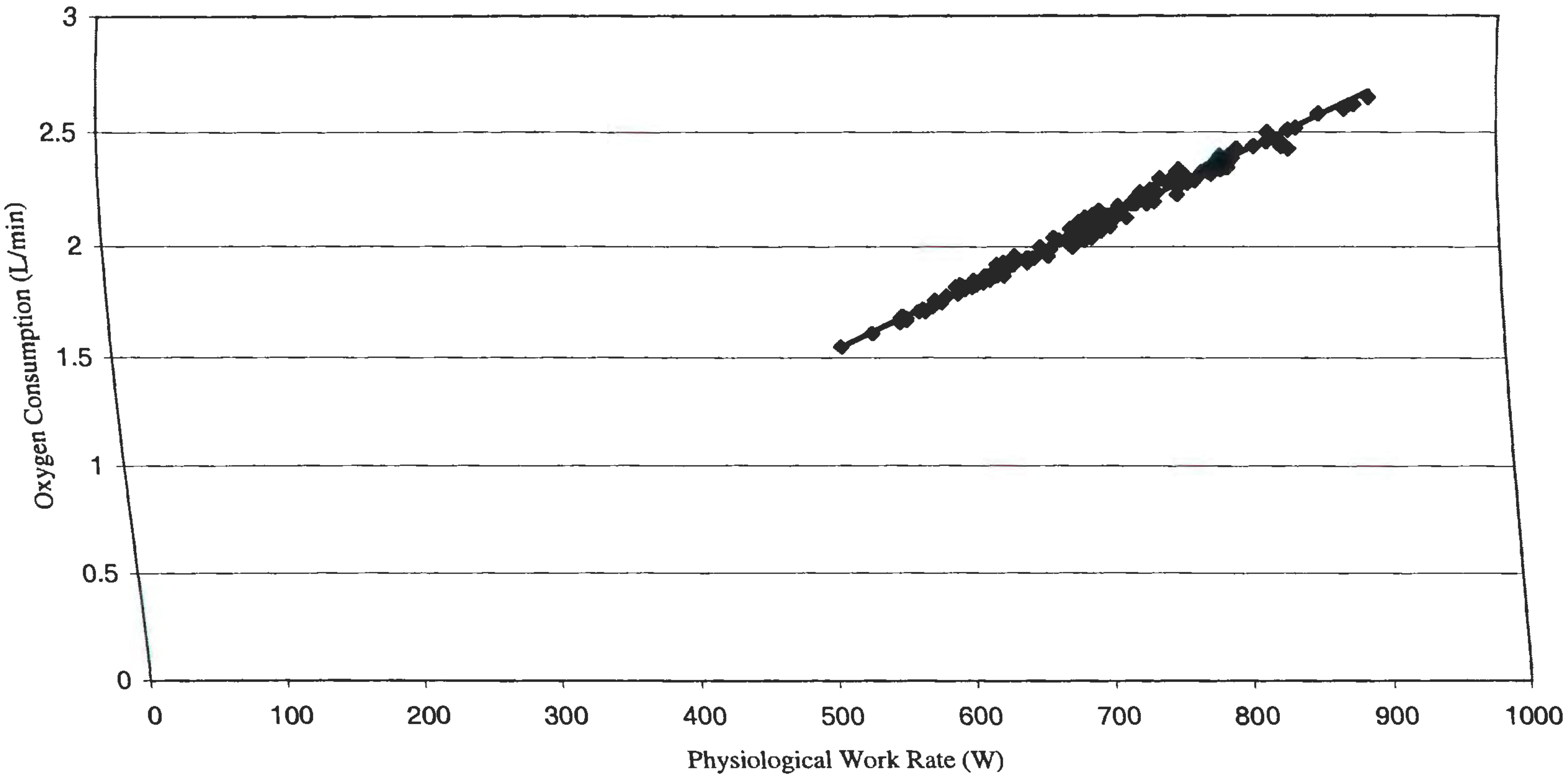

Figure 10. Validation data and the regression line.

The plot of the data from Cloud (1984) and the regression line is shown in Figure 11. The data lie along the line and slightly below it. It appeared that equation 56 under-predicted the data. However, the percent errors ranged from –1.4% to 6.6%, so the errors were very small.

Astrand and Rodahl (1970) showed that the oxygen consumption was a linear function of the physiological work rate. Their graph provided the idea for relating oxygen consumption to physiological work rate only. An equation fit to their data revealed a slope of 0.002936, which is very close to that obtained in equation 55.

Equation 55 does not directly take the respiratory exchange ratio into account. However, it does provide accurate predictions of oxygen consumption based on physiological work rate and it agrees with the information presented in Astrand and Rodahl (1970).

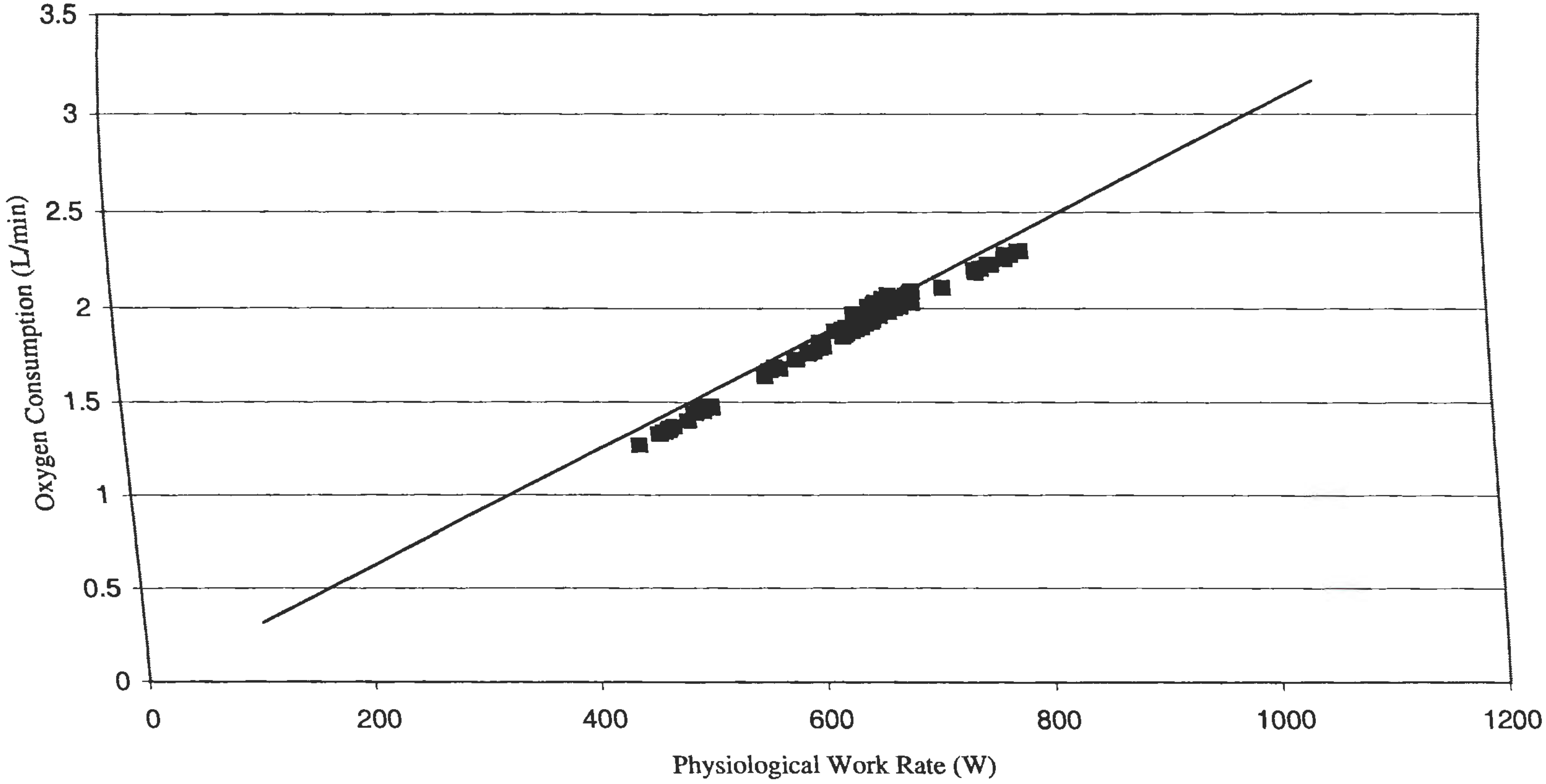

Figure 11. Data from a validation study plotted along the regression line for the zero-intercept model.

Anaerobic Threshold

Some studies (Dwyer and Bybee, 1983; Rusko et al., 1980; Thorland et al., 1980; Weltman and Katch, 1979) had shown a relationship between anaerobic threshold (AT) and maximal oxygen consumption. It was desired to see if there were the same relationship for a larger group of subjects. The percentage of maximal oxygen consumption at which the anaerobic threshold occurs (AT%) and the difference between maximal oxygen consumption and the AT (V_{O2max}-AT) were considered also. Oxygen consumption and anaerobic threshold were considered in both relative (mL/kg/min) and absolute (L/min) terms. As the AT has been shown to be related to fitness level (Claiborne, 1984), the possibility that AT may be related to other factors such as height, weight, or body mass index (BMI) was evaluated using multiple regression.

The equations resulting from the linear and multiple regressions are shown in Tables 9 and 10.

Table 9. Linear equations obtained from relating AT%, AT, and V_{O2max}-AT difference (Diff) to relative and absolute oxygen consumption. Relative oxygen consumption is in units of ml/kg/min, while absolute oxygen consumption is in L/min.

Equation Units	Number of Cases	Equation	R
Relative	120	$AT\% = 0.3682\ V_{O2max} + 52.935$ (57)	0.3006
Relative	120	$AT = 0.8624\ V_{O2max} - 7.1585$ (58)	0.8305
Relative	120	$Diff = 0.1376\ V_{O2max} + 7.1585$ (59)	0.2314
Absolute	168	$AT\% = 0.6462\ V_{O2max} + 62.275$ (60)	0.0435
Absolute	168	$AT = 0.6083\ V_{O2max} + 0.1445$ (61)	0.7964
Absolute	168	$Diff = 0.0632\ V_{O2max} + 1.2054$ (62)	0.0511

Table 10. Multiple regression equations obtained from stepwise regression of AT%, AT, and V_{O2max}-AT difference (Diff) on age, height, weight (WT), BMI, and V_{O2max} in relative and absolute terms. Relative oxygen consumption is in units of ml/kg/min, while absolute oxygen consumption is in L/min.

Equation Units	Number of Cases	Equation	R
Relative	120	$AT\% = 92.4782 - 0.3585WT$ (63)	0.3873
Relative	120	$AT = 13.8534 + 0.625V_{O2max} - 0.1661WT$ (64)	0.7356
Relative	120	$Diff = -13.8534 + 0.3750V_{O2max} - 0.1661WT$ (65)	0.5627
Absolute	168	$AT\% = 78.427 + 6.0138\ V_{O2max} - 0.3836WT$ (66)	0.4755
Absolute	168	$AT = 0.0297 + 0.7156V_{O2max}$ (67)	0.7320
Absolute	168	$Diff = -2.0768 + 0.5910V_{O2max} - 0.0771WT$ (68)	0.8125

Equations 58, 61, 64, and 68 were selected for further statistical analysis. The results are summarized in Table 11.

Table 11. Results from statistical tests to evaluate competing models. The intercept of the linear equation is noted with the subscript 0 while slope coefficients are noted with the subscripts 1 (V_{O2max}) and 2 (WT).

	Eqn . 58	Eqn. 61	Eqn. 64	Eqn. 68
S_e/S_y	0.559	0.607	0.688	0.592
R	0.831	0.796	0.736	0.813
$S_e(b_0)/b_0$	0.365	0.755	0.373	0.046
$S_e(b_1)/b_1$	0.052	0.059	0.273	0.043
$S_e(b_2)/b_2$			0.135	0.266
t_1	0.831	0.796	0.312	1.714
t_2			0.631	0.275
bias	0.000	-0.021	0.000	-0.631
Graph of residuals	No pattern	No pattern	No pattern	No pattern
% of errors (#) > ± 20%	27% (32)	32% (54)	25% (17)	90% (60)
% of errors (#) > ± 40%	6% (7)	11% (19)	10% (7)	66% (44)
% of errors (#) > ± 100%	0% (1)	2% (4)	1% (1)	27% (18)

The slope coefficients related to V_{O2max} in all four equations are positive, indicating that when the V_{O2max} increases, the AT will increase also. Thus, the sign of these slope coefficients is rational. The slope coefficients for weight in the two multiple regression equations are negative, indicating that when weight increases, the AT or the V_{O2max}-AT difference decrease. When weight increases due to an increase in body fat, a subject may not be as fit. The AT occurs at higher values for fitter individuals (Claiborne, 1984). However, increased weight may occur when lean muscle mass increases through training. So, the rationality of the sign of the slope coefficients for weight is hard to assess.

When the standard error of the regression coefficient (lines 3-5 in Table 10) is greater than 0.3 to 0.4, McCuen (1993) has found from experience that the coefficient is of questionable accuracy. Therefore, the intercept coefficients (line 3) in both equations 58 and 64 are of borderline questionable accuracy. The intercept coefficient in equation 61 is inaccurate, while the intercept coefficient in equation 68 is accurate. The slope coefficients (lines 4-5) are all less than 0.3 and are thus accurate.

A partial regression coefficient (lines 6 and 7) close to one indicates an important predictor, while a coefficient near zero indicates an unimportant predictor. Thus, maximal oxygen consumption was an important predictor of AT in both linear equations (line 6). The partial regression coefficients for equation 64 indicated that weight was not as important a predictor as maximal oxygen consumption but that both variables were important. Equation 68 has a partial regression coefficient greater than one (line 6). This meant that there were significant intercorrelations between the predictors. It is recommended (McCuen, 1993) that such a model not be used.

For standard error ratios less than one, the model provides an improvement over predictions made with the mean. The standard error ratios for the four equations indicated that prediction accuracy could be improved by using the models in equations 58, 61, 64, and 68.

The bias of a model should be close to zero. A positive bias indicates that a model consistently overpredicts, while a negative bias shows underprediction. Equations 58 and 64 have zero biases while equations 61 and 68 have negative biases.

The plots of the residuals against the independent variables showed that there were no patterns to the residuals (see Appendix B, Figures 72 to 77). This indicated a constant variance.

The number and percent of errors greater than ± 20%, ± 40%, and ± 100% show that the errors produced by equation 68 are quite large. Ninety-percent of the predictions are in error by more than 20%. The other three equations have similar percentages of errors greater than 20%, 40%, and 100%.

The model in equation 61 was eliminated because of the inaccurate intercept coefficient and the model bias. Due to model bias and large percent errors in prediction, equation 68 was eliminated also. The models in equations 58 and 64 have intercept coefficients that are of borderline questionable accuracy, zero biases, and similar percent errors in prediction. However, based on the standard error ratio, equation 58 provided a larger improvement in prediction accuracy over the standard deviation (0.559) compared to equation 64 (0.688). Therefore, equation 58 was selected. The anaerobic threshold was related to the maximal oxygen consumption by:

$$AT = 0.8624V_{O2max} - 7.1585 \quad (58)$$

where: AT, anaerobic threshold, mL/kg/min

V_{O2max}, maximal oxygen consumption, mL/kg/min

A plot of the data and equation 58 are shown in Figure 12.

Anaerobic threshold data was obtained for subjects who completed a study on the effects of exhalation resistance in a respirator on performance of the wearer (Caretti et al., 2001). Additional data was obtained from Powers et al. (1984). Figure 13 shows this data overlayed onto a plot of equation 58 and the data used to obtain it. The new data is consistent with the data used to develop the equation.

Equation 58 consistently overpredicts the anaerobic threshold for Caretti et al. (2001) and underpredicts for most of the Powers et al. (1984) data. The percent error in the residuals for the Caretti et al. (2001) data ranged from –29 to 9% while that for Powers et al. (1984) ranged from –6 to 67%. For the two validation studies combined, 38% of the errors are greater than 20%, 17% are greater than 40%, and 0% are greater than 100%. These prediction errors are higher than those for the original data used to develop equation 58. However, this does show that 83% of the predicted values are within 40% of the actual values. Considering the correlation coefficient of equation 58, the coefficient with the borderline questionable value, and the highly scattered data, these errors are reasonable.

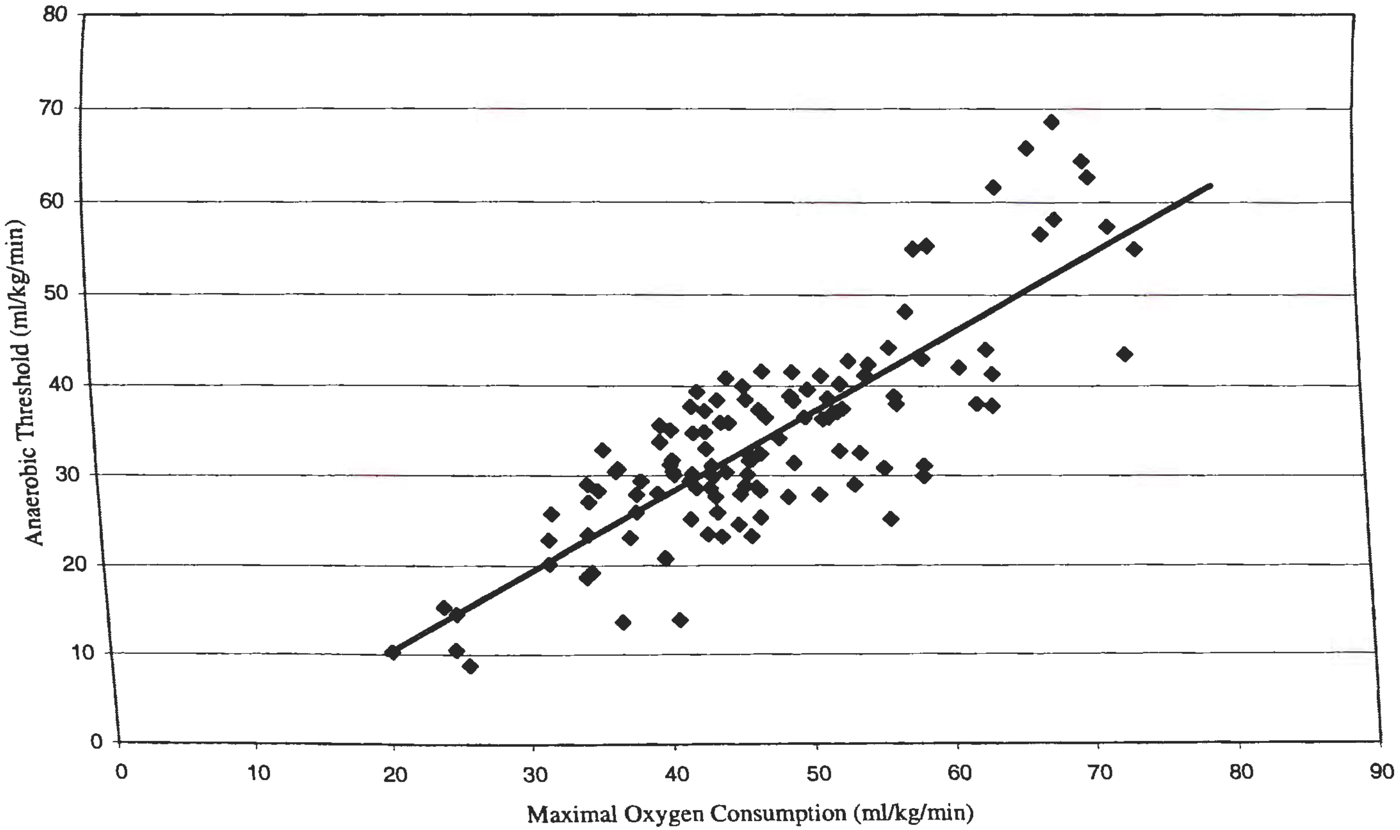

Figure 12. Relative anaerobic threshold plotted against maximal oxygen consumption. Shown is the best fit line.

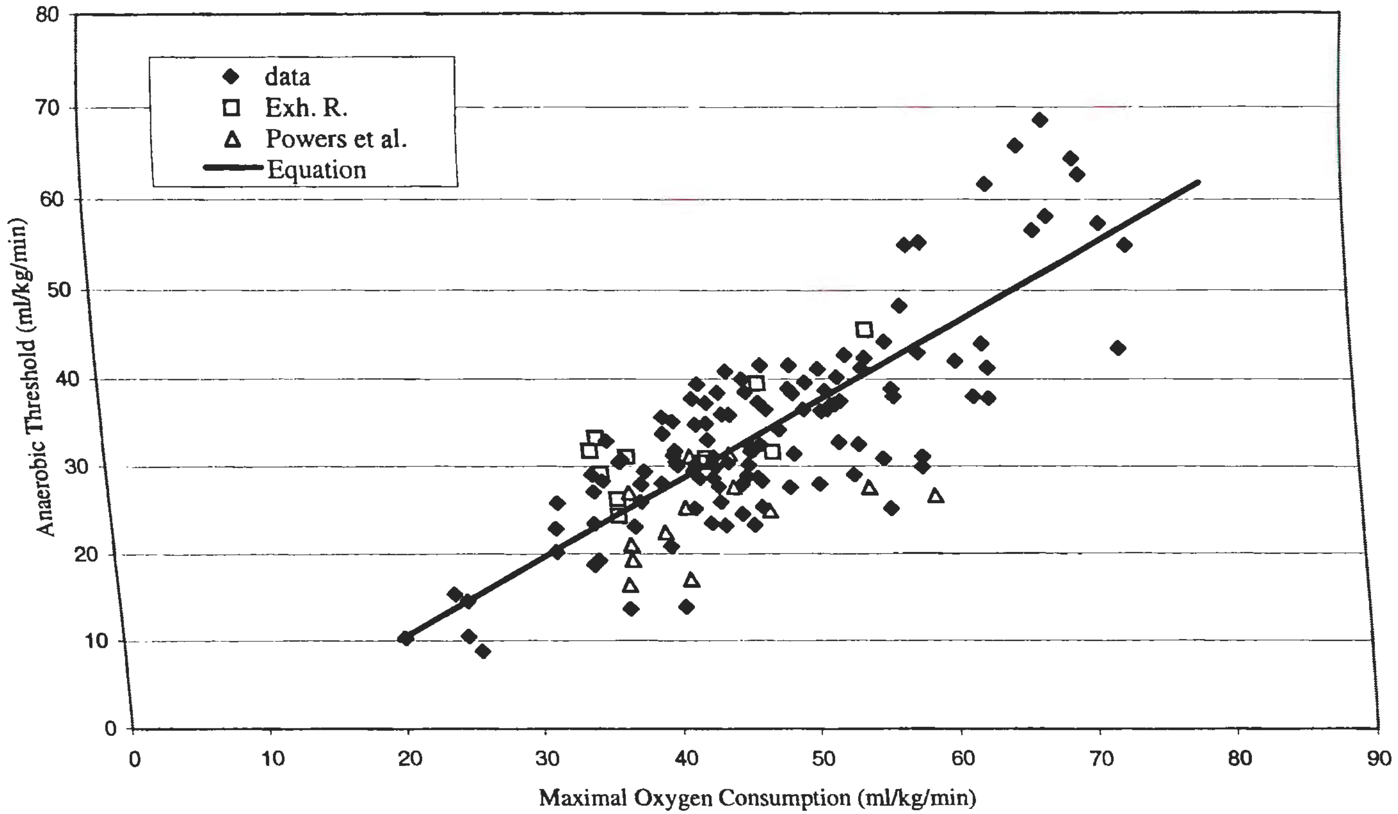

Figure 13. Validation data shown with the original data and the best fit line.

An equation can be fit to the validation data and the slope and intercept of the equation compared to the slope and intercept equation obtained from calibration. This was not done because of the small amount of data and the variability in that data.

The high correlation coefficient shows that the model fit the data well over the whole range of subjects. But, looking at any individual point, there may be a large error. This error is due in part to the heterogeneity of the data. This heterogeneity is evident even when looking just at one gender, one training status, and one small age range. For instance, Powers et al. (1984) looked at thirteen trained males and found that the AT occurred at 41 to 74% of V_{O2max}. So, even when a relatively homogeneous group is considered, the AT data is heterogeneous.

Multiple regression equations were evaluated because it seemed likely that AT may have depended on more than just the V_{O2max}. Part of the scatter may have been due to this other factor or factors. However, these equations provided less accurate predictions than the linear equation selected.

The correlation coefficient of 0.83 found in this study was consistent with the results from Dwyer and Bybee (1983) ($r = 0.87$), Rusko et al. (1980) ($r = 0.61$), Thorland et al. (1980) ($r = 0.81$), and Weltman and Katch (1979) ($r = 0.81$). The subjects used in the previous studies included females and males that were recreational athletes or highly trained athletes. The present study included subjects with training statuses from sedentary to highly trained. Thus the relationship between AT and V_{O2max} appears to hold regardless of training status. The inclusion of sedentary individuals in the present study allows the results to be applied to a broader range of subjects. Respirator wearers are probably not highly trained athletes, so the inclusion of sedentary people, recreational athletes and highly trained athletes should make the equation more applicable to actual respirator wearers. As the AT has been shown to be unaffected by respirator wear (Johnson et al., 1995), equation 58 applies to both respirator wearers and unencumbered subjects.

Minute Ventilation as a Function of Oxygen Consumption

Based on predictions from equation 58, the eight subjects in this study had one stage above the anaerobic threshold. Typical curves are shown for subjects 214 and 231 in Figures 14 and 15. (For plots of the data for the other subjects, see Appendix B, Figures 78 to 83.) The selected curves were used because a linear relationship below the AT and an exponential relationship above the AT had been seen for progressive exercise (Martin and Weil, 1979). So, these curves were used to see if the same relationships held for constant-rate exercise. With only one point above the anaerobic threshold, it was difficult to assess whether an exponential curve was the best fit. There were four data points below the anaerobic threshold. While the correlation coefficients were high, this is due in part to the small number of data points. By examining the line itself through the data points, the fit of the equation was observed. For many of the subjects, it appeared that there was a curvilinear relationship below and above the anaerobic threshold.

The linear curves fit to the data below the anaerobic threshold had slopes that ranged from 17.544 to 34.519 and intercepts that ranged from –21.34 to 2.56. The

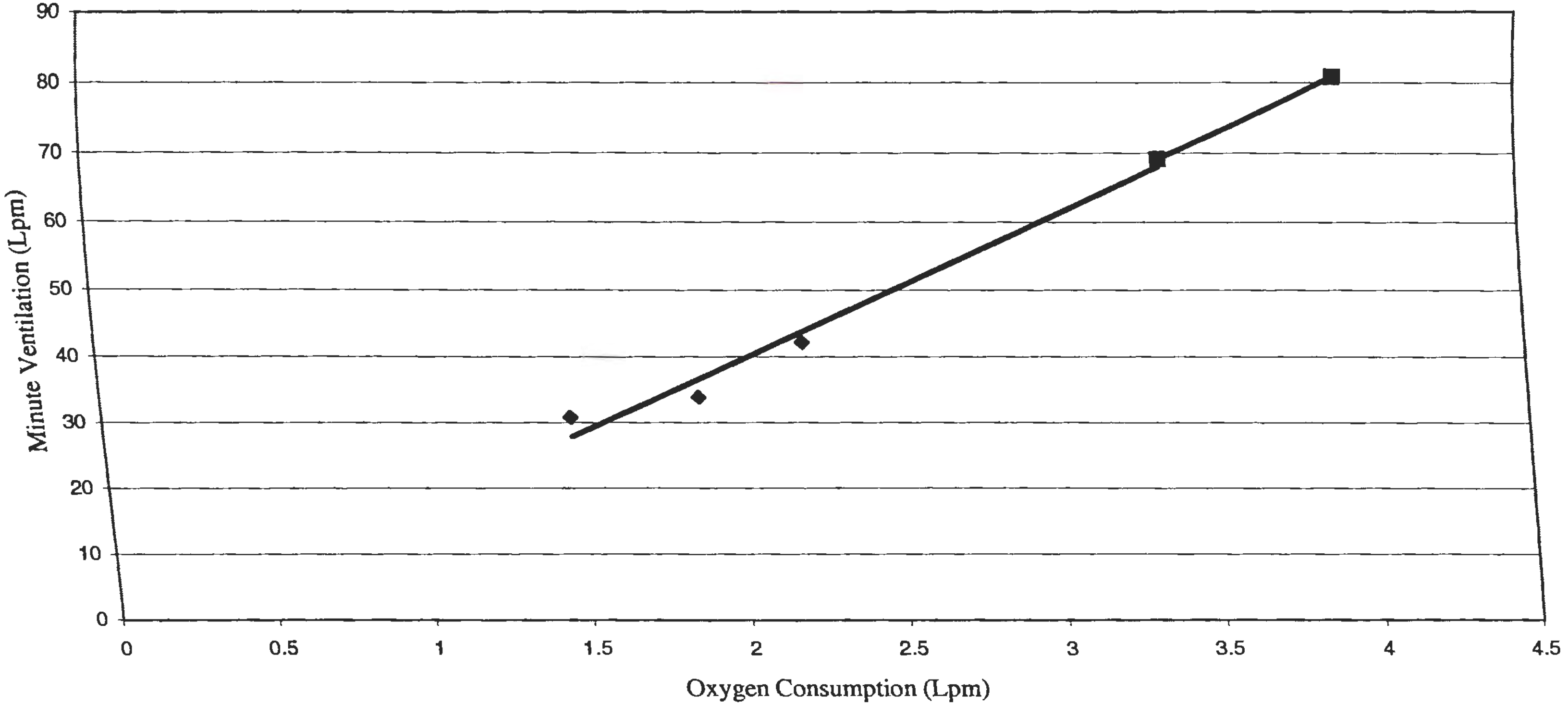

Figure 14. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 214.

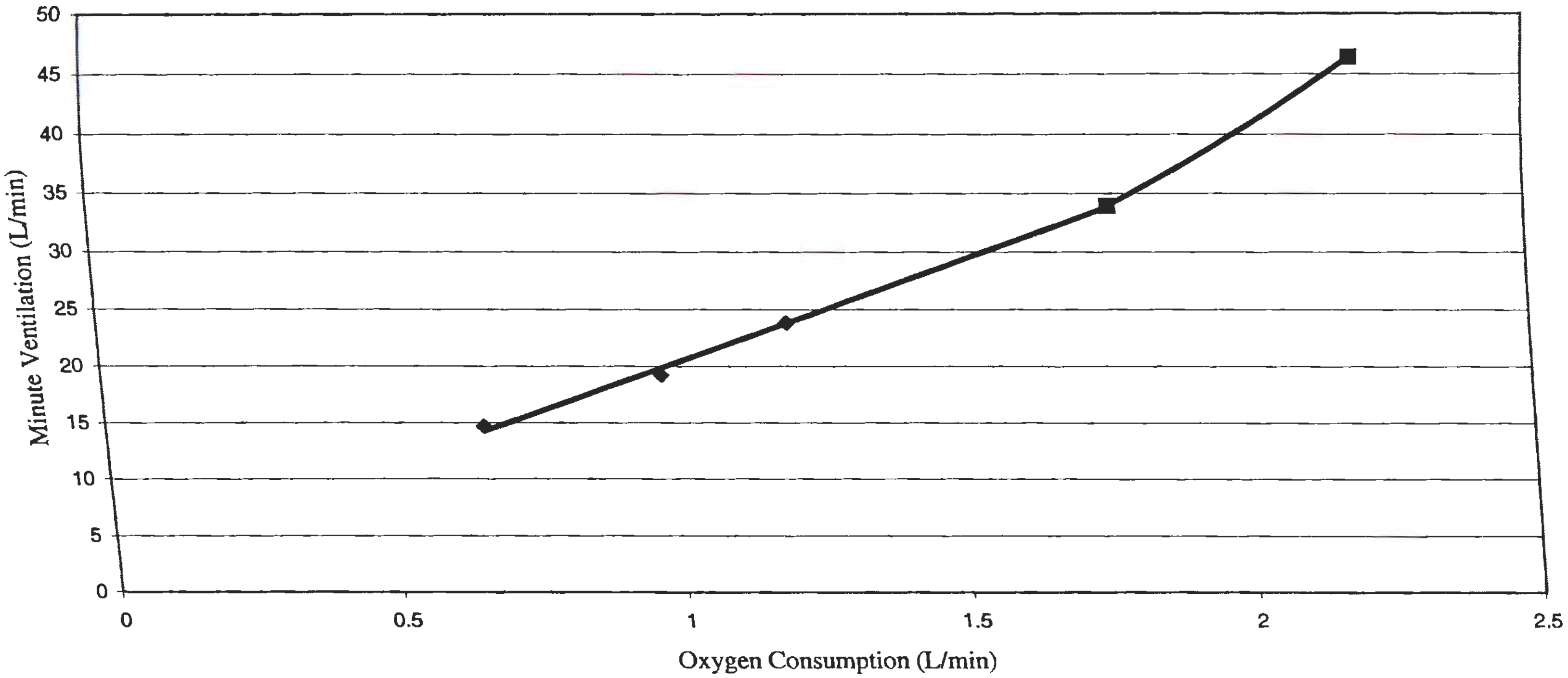

Figure 15. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 231.

slopes for the exponential curves ranged from 0.29 to 1.04 while the intercepts ranged from 6.28 to 26.15. As the exponential curves were fit to two points, it was expected that there would be a lot of variability in the slope and intercept coefficients. However, the coefficients for the linear portion showed a lot of variability also. This variability is not surprising considering the variability in the data itself. For a V_{O2} of 3 L/min, subject 001 had a minute ventilation around 64 L/min while subject 145 had a minute ventilation of 105 L/min. If V_{O2} were expressed as $\%V_{O2max}$, there was still a lot of variability. At 80-85% of V_{O2max}, subject 001 had a minute ventilation of 92 L/min while subject 002 had a minute ventilation of 38 L/min. Clearly, predicting minute ventilation from oxygen consumption alone would not give good results.

So, the problem was the data seemed to yield similar shaped curves, but the slope and intercept coefficients were vastly different. As $\%V_{O2max}$ is used to make comparisons among different subjects, it was decided to evaluate whether a $\%V_{Emax}$ would be beneficial to make comparisons. So, the V_{Emax} was obtained from each subject's V_{O2max} test. (See Appendix B, Figures 84 to 91 for plots of the data.)

The data were now all on a relative scale and were thus combined. Figure 16 shows a plot of the data. Because the relationship between the variables was unknown, linear ($y = ax + b$), quadratic ($y = ax^2 + bx + c$), exponential ($y = ae^b$), and power ($y = ax^b$) models were fit to the data. The statistics for the four models are shown in Table 12.

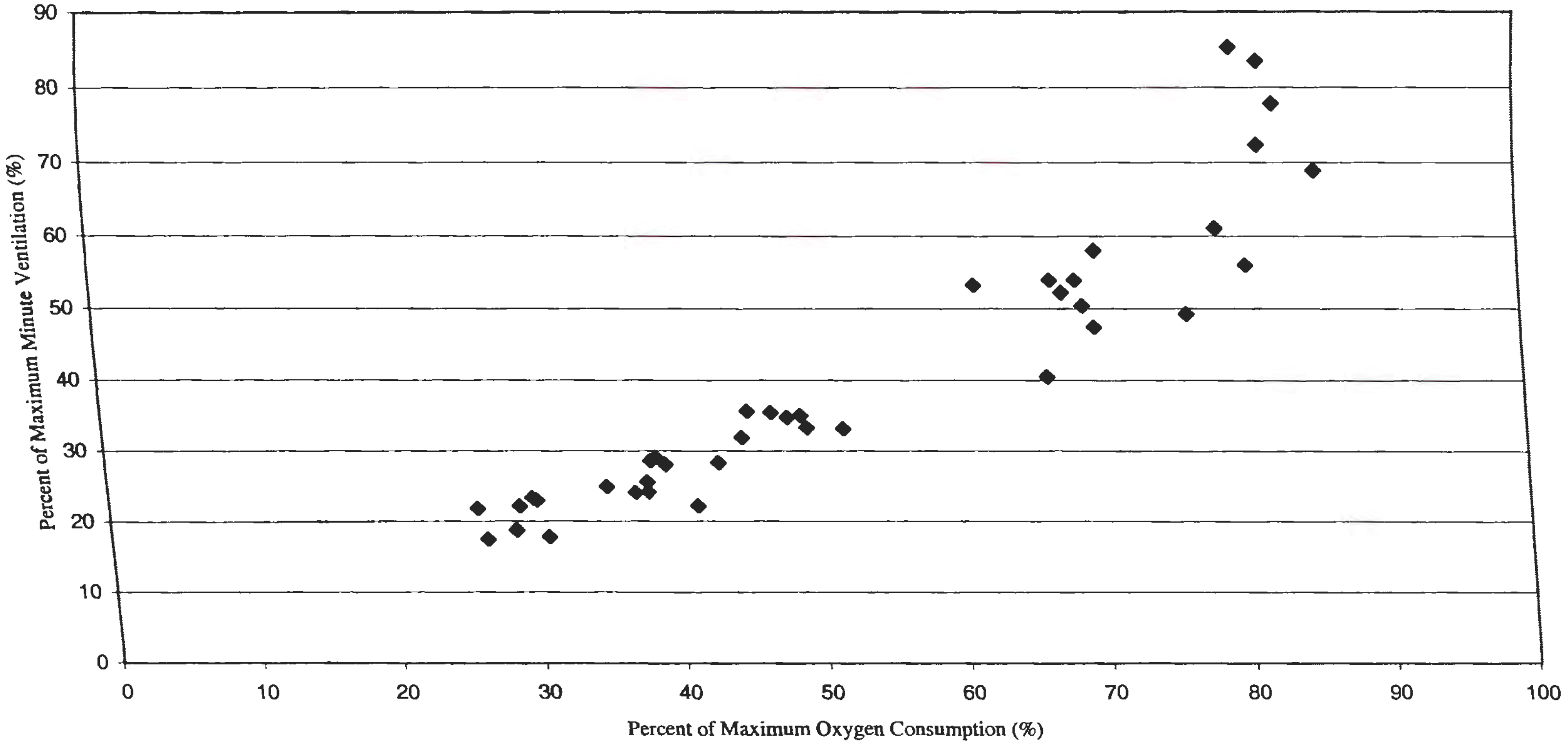

Figure 16. Percent of maximum minute ventilation versus percent of maximum oxygen consumption for all subjects combined.

Table 12. Standard error ratio, bias, mean bias, and correlation coefficient for the linear, quadratic, exponential, and power models.

	Linear	Quadratic	Exponential	Power
S_e/S_y	0.342	0.133	0.311	0.343
Bias	-0.001	0.147	-0.263	-0.511
Mean bias	0	0.004	-0.006	-0.013
R	0.941	0.951	0.966	0.959

The correlation coefficient for each model was high. The standard error ratios for the four models indicated that each provided a significant improvement over predictions made with the mean. Each of the models had a bias. The quadratic equation over-predicted (positive bias) while the linear, exponential and power models under-predicted (negative bias).

A model should generally not be used beyond the range over which it was developed. However, no data was collected at work rates higher than 80-85% of V_{O2max}. The overall model that is being developed to predict the pulmonary effects of respirator wear during physical activity will include higher work rates. The predicted $\%V_{Emax}$ was determined for $100\%V_{O2max}$ to evaluate the applicability of the three models to higher work rates. The $\%V_{Emax}$ for the linear, quadratic, exponential, and power models were 83.5%, 98.85%, 104.84%, and 81.66%, respectively. The linear and power models do not come close to predicting $100\%V_{Emax}$ for $100\%V_{O2max}$, while the exponential and quadratic models do. The linear and power models were rejected because of this.

The quadratic model had a lower standard error ratio and a smaller bias. The exponential model had a higher correlation coefficient and a lower average percent error (0.73% compared to 1.71%). However, the values for each of the statistics were close. There was no clear distinction between the quadratic and exponential models. The quadratic model was selected because of the slightly better statistics. The $\%V_{Emax}$ was predicted from the following equation:

$$\%V_{E\max} = 0.0095 \cdot \%V^2_{O2\max} - 0.133 \cdot \%V_{O2\max} + 17.153 \qquad (69)$$

A plot of the data and the regression curve are shown in Figure 17. (See Appendix B, Figures 92 to 94 for plots of the linear, exponential, and power models.)

The data from the two validation subjects are plotted on a graph of equation 69 shown in Figure 18. The percent errors ranged from –22% to –3%. For these two subjects, the residuals (see Appendix B, Figure 95) and the percent errors showed that the model consistently under-predicted the $\%V_{Emax}$. However, these errors were not large considering the variability of the data.

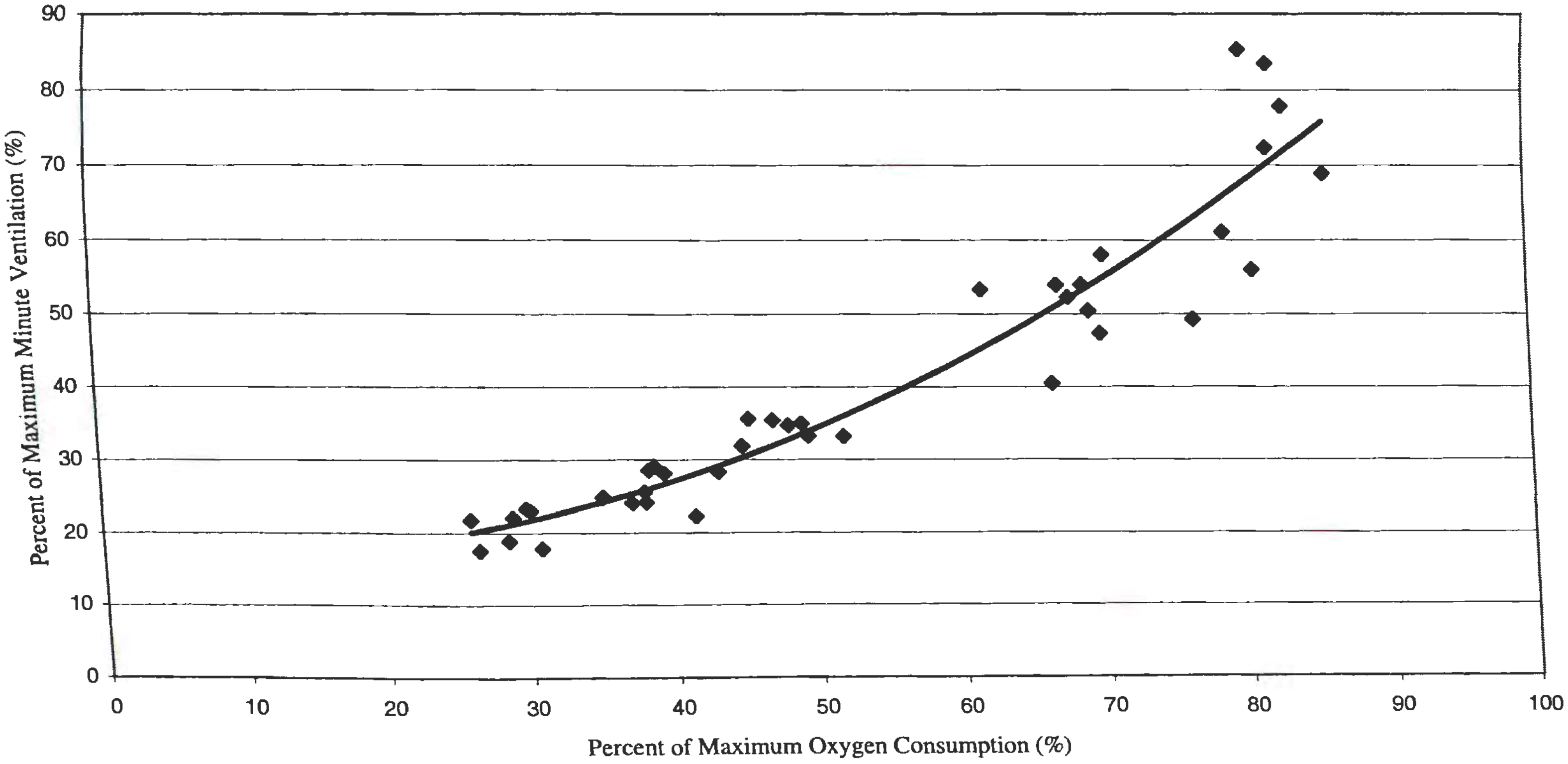

Figure 17. Percent of maximum minute ventilation versus percent of maximum oxygen consumption for all subjects combined. Shown is the best-fit quadratic model.

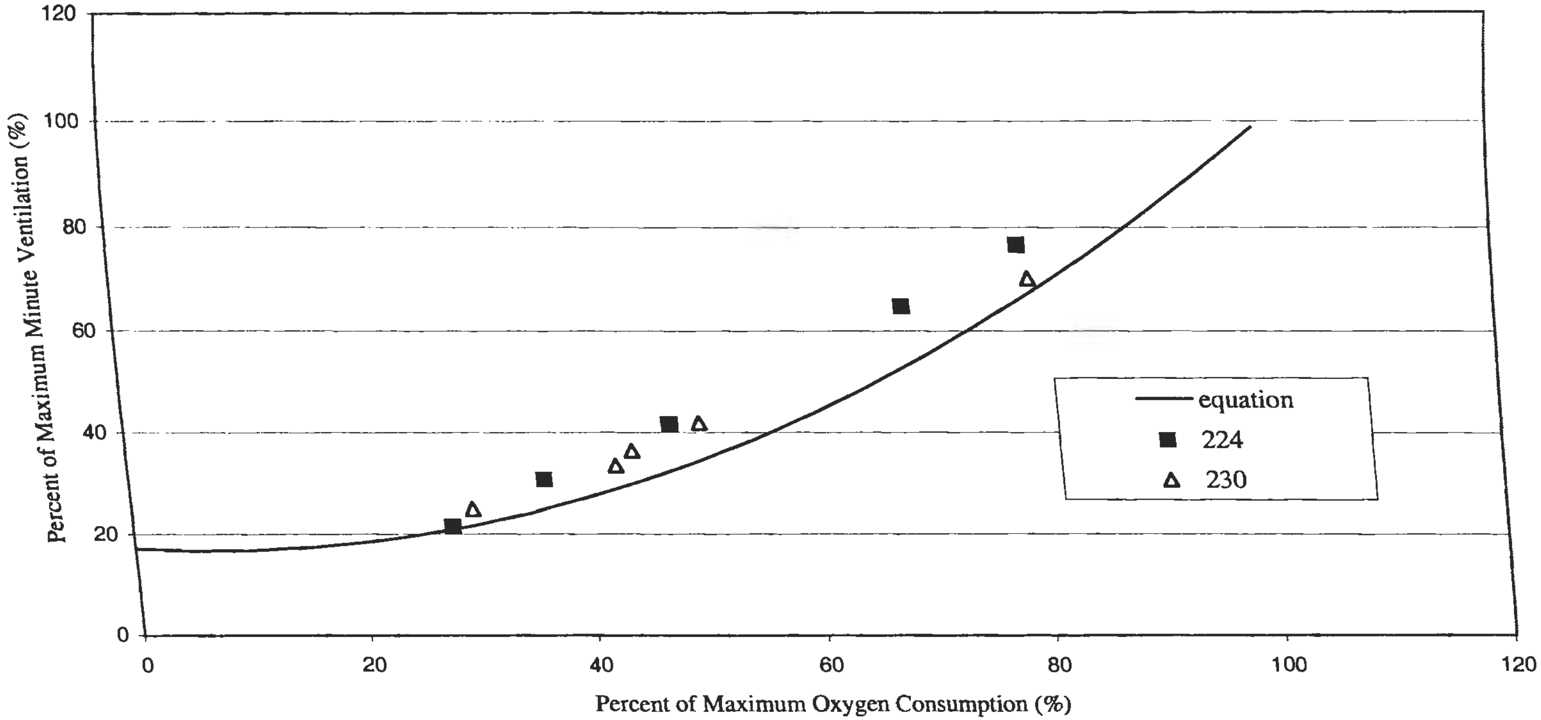

Figure 18. Validation data from two subjects plotted against the quadratic model relating percent of maximum minute ventilation to percent of maximum oxygen consumption.

Determining V_{Emax}. Equation 69 related the percent of maximum minute ventilation to the percent of maximum oxygen consumption. Maximum oxygen consumption is determined from a common test and is reported in the literature. If the required oxygen consumption is determined using equation 55, then the right-hand side of equation 69 can be determined by dividing the required oxygen consumption by the maximum oxygen consumption. The percent of maximum minute ventilation can be obtained from equation 69. In order to determine the minute ventilation, the maximum minute ventilation is required. This can be obtained during the same test used to determine the maximum oxygen consumption. However, it is not reported commonly. A way of determining the maximum minute ventilation was needed.

The maximum minute ventilation (V_{Emax}) was obtained for the subjects in the current study and a regression performed (see Appendix B, Figure 96). The high correlation coefficient (0.898) indicated that there was a strong relationship between the V_{Emax} and V_{O2max}.

Data were obtained from studies conducted by Johnson et al. (1999) and Caretti et al. (2001). The data were sorted in ascending order by V_{O2max} and then every third data point was removed and set aside for validation. The calibration data are shown in Figure 19. The regression equation was:

$$V_{Emax} = 20.01 V_{O2max} + 27.855 \tag{70}$$

where: V_{Emax}, maximum minute ventilation, L/min

V_{O2max}, maximum oxygen consumption, L/min

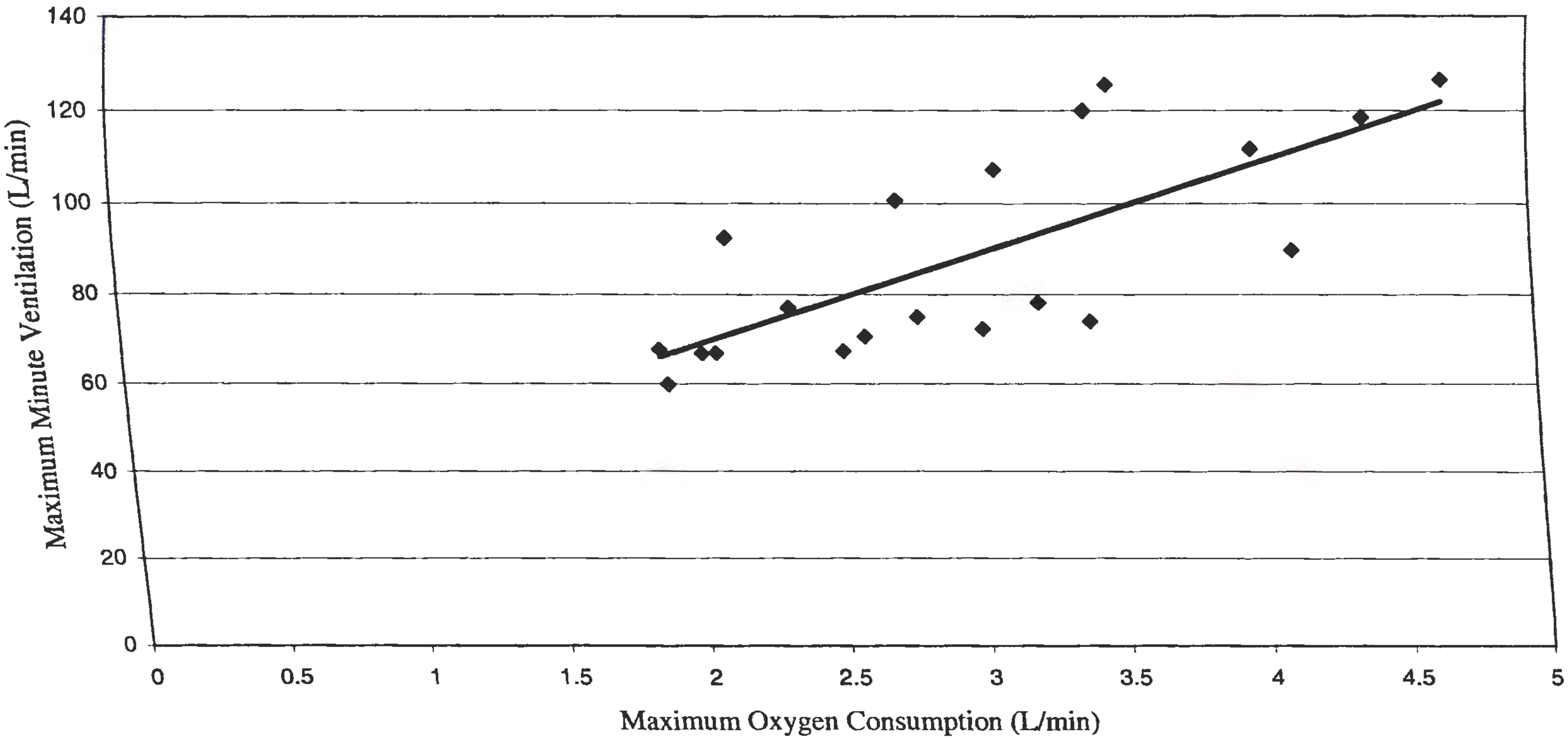

Figure 19. Calibration data for maximum minute ventilation versus maximum oxygen consumption. Shown is the best fit line.

The correlation coefficient (0.751) was lower than that obtained from the current study (0.898). This showed that small data sets should not be used to fit physiological data due to the large variability in the data.

The ratio of the standard error to the standard deviation (S_e/S_y) was 0.678, which indicated that the model provided an improvement over the mean in making predictions. The ratio of the standard error to the coefficient ($S_e(b_i)/b_i$) for the slope and intercept coefficient were 0.207 and 0.467, respectively. McCuen (1993) has found that when the ratio is greater than 0.3 to 0.4, the coefficient is of questionable accuracy. The partial regression coefficient (t_1) was 0.751, which indicated that the slope coefficient was a strong predictor. The model bias and mean bias were –0.001 and –1.4E-5. These low values showed that the model made slightly biased predictions. However, the bias was very small. There was no pattern to the residuals (see Appendix B, Figure 97).

The validation data and the linear regression line were shown in Figure 20. The regression equation was:

$$V_{Emax} = 20.476 V_{O2max} + 33.396 \tag{71}$$

The correlation coefficient was 0.823. The calculated t-values for the slope and intercept coefficients were 0.357 and 0.332, respectively. The null hypothesis was accepted for both coefficients. That is, the slope and intercept coefficients from the calibration and validation data were not statistically different.

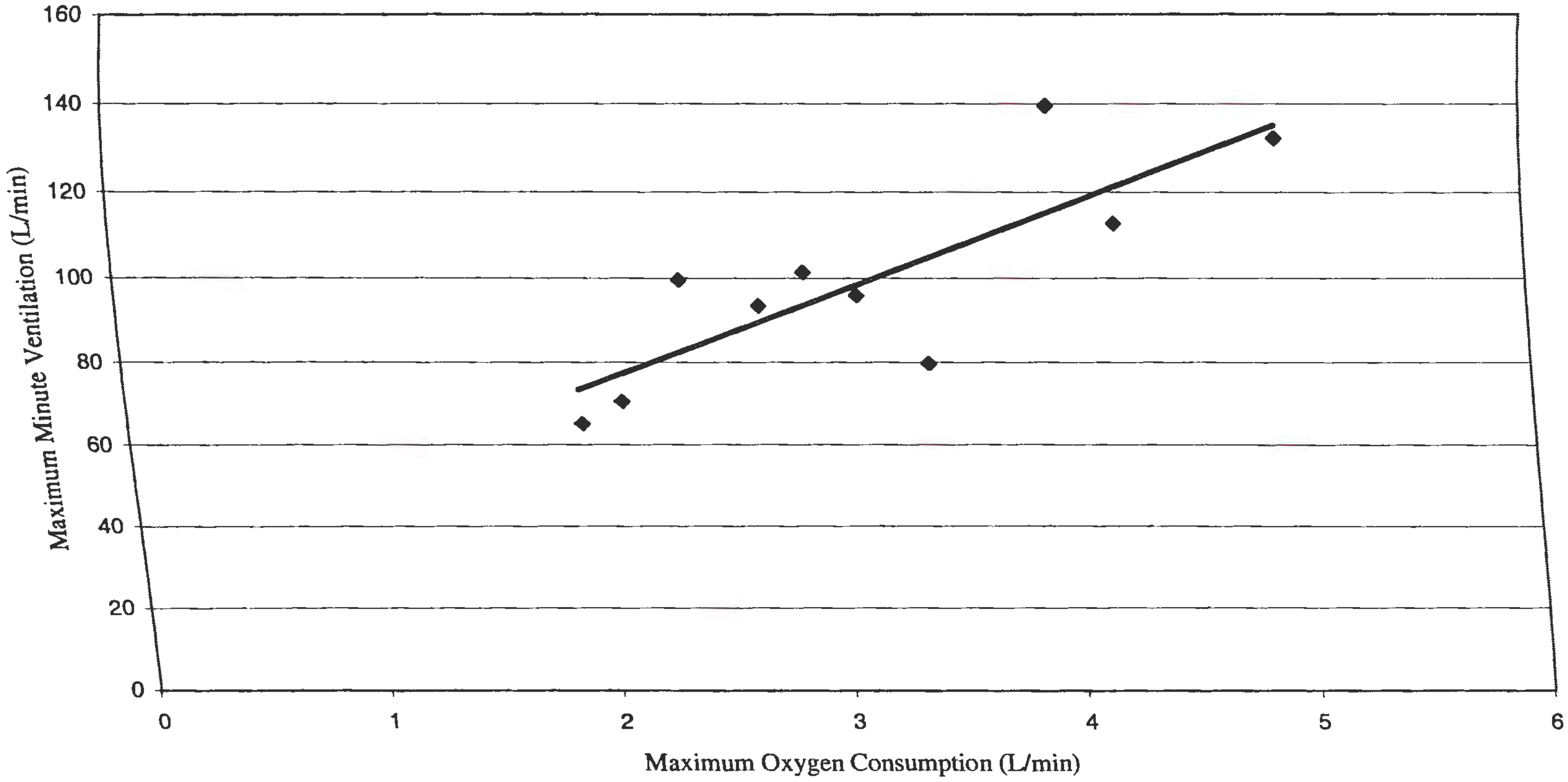

Figure 20. Validation data for maximum minute ventilation versus maximum oxygen consumption . Shown is the best fit line.

All statistics for the calibration equation (equation 70) except for the standard error ratio of the intercept coefficient (0.467) indicated that it provided accurate predictions of V_{Emax} from V_{O2max}. McCuen (1993) has found from experience that a coefficient had questionable accuracy when the standard error ratio for a coefficient was greater than 0.3 to 0.4. While the intercept coefficient was of questionable accuracy, it was statistically the same as the intercept coefficient from the validation equation. The fact that the model provided an improvement over the mean ($S_e/S_y <$ 1.0), the slope coefficient was an important predictor, the model was unbiased, and there was no pattern to the residuals indicated that overall, equation 70 provided accurate predictions.

An equation was obtained relating percent of maximum minute ventilation to percent of maximum oxygen consumption. While it is important to know that the minute ventilation versus oxygen consumption curve is linear below the AT and exponential above the AT, that relationship does not help in making predictions of minute ventilation for a given oxygen consumption. This is because two subjects are likely to have very different minute ventilations for the same oxygen consumption. This is true whether the oxygen consumption is expressed in L/min, ml/kg/min, or $\%V_{O2max}$. Thus a way to relate an individual's minute ventilation to his or her oxygen consumption was obtained by finding $\%V_{Emax}$ as a function of $\%V_{O2max}$.

In order to use equation 69, a way of relating V_{Emax} to V_{O2max} was required. This was accomplished by relating the maximum V_E recorded during a V_{O2max} test to the V_{O2max}. A good fit was obtained.

It had been mentioned that large data sets should be used when fitting empirical curves to physiological data due to the large variability in the data. Only eight subjects were used to fit equation 70. However, there was no additional data available. A search of the literature showed no one else who had presented the relationship between minute ventilation and oxygen consumption in the same way. In order to have included more subjects, the V_{Emax} was required. It is not common to report this variable. For instances where V_{O2} and V_E data would be reported, such as in graduate theses where different V_{O2} max tests were compared, no additional constant-rate exercise tests were performed. So, there were no additional data that could have been included.

Equation 69 was developed over a work range of 25 – 85%. Work rates in the overall model will include work rates outside this range. Generally, a model should not be used outside the range over which it was developed (McCuen, 1993). However, as there were no additional data available, equation 69 was used for other work rates. For this reason, one of the selection criteria was the $\%V_{Emax}$ predicted by each equation for $100\%V_{O2max}$. Models that did not predict a $\%V_{Emax}$ near 100% were rejected. No other validation outside the 25-85% range was possible. Certainly, data should be obtained on more subjects over a broader range of work rates to determine how well equation 69 makes predictions for a larger population. For now, this equation was the best one available, but this lack of data could limit the expected accuracy of model results.

Tidal Volume as a Function of Oxygen Consumption

The plots of steady state tidal volume versus steady state oxygen consumption are shown for two typical subjects in Figures 21 and 22 (see Appendix B, Figures 98 to 103 for the plots for the other subjects). The relationship between the variables for four of the subjects (023, 145, 173, and 214) was curvilinear. The other four subjects had different patterns. The plot for subject 001 showed that there might be a linear relationship up to a point where the tidal volume leveled off. This was the relationship reported by Martin and Weil (1979) for subjects undergoing incremental exercise. However, their subjects had linear curves up to the anaerobic threshold, with tidal volume plateauing above the anaerobic threshold. For subject 001, the plateau appears before the anaerobic threshold. Martin and Weil (1979) did state that not all subjects exhibited the same pattern.

The steady state tidal volume values were obtained when oxygen consumption reached a steady state. While minute ventilation was also at a steady state, tidal volume was often quite variable particularly at the lower work rates. At the higher work rates, there was less variability in the 30-sec tidal volumes. These differences are probably due to the fact that the subjects had more willful control over their ventilation at the lower work rates than at the higher rates. The differences in the patterns of tidal volume versus oxygen consumption are likely to be due to the non-steady state values of tidal volume for some of the subjects at the lower work rates.

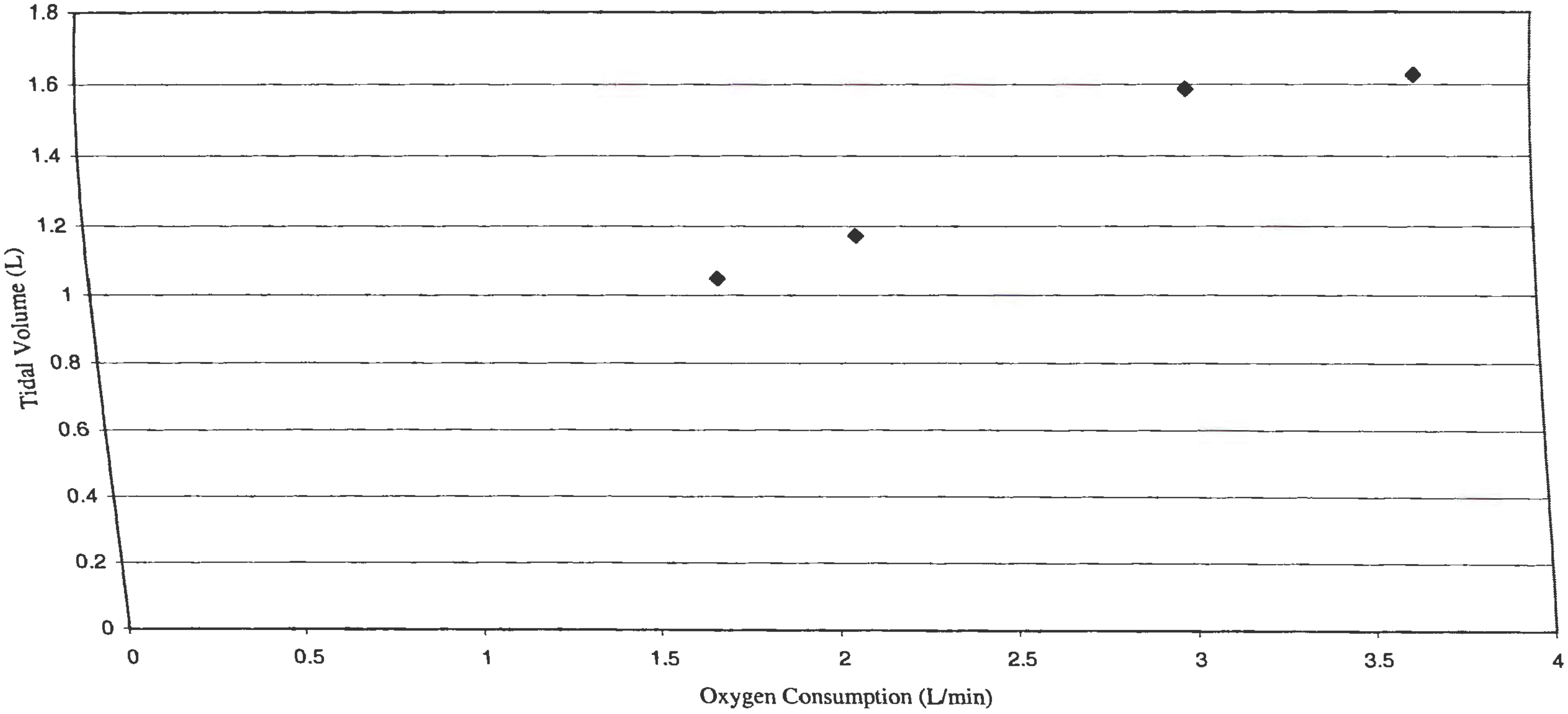

Figure 21. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 001.

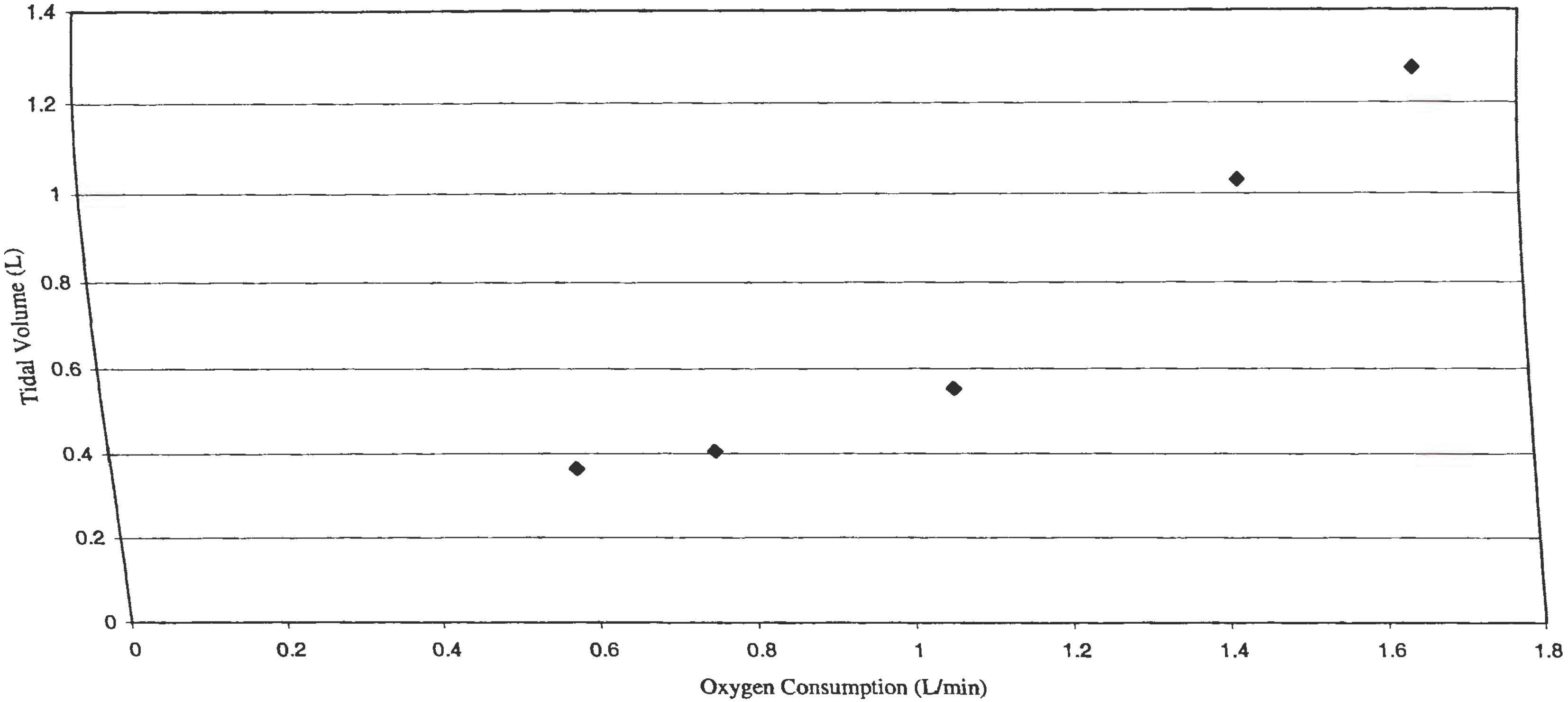

Figure 22. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 023.

The tidal volume at a given oxygen consumption varied by subject. A way of relating the tidal volume to oxygen consumption independent of the particular subject was necessary. The maximum tidal volume was obtained for each subject. These varied from 1.43 to 3.16 L. The $\%V_{Tmax}$ and $\%V_{O2max}$ were obtained. (See Appendix B, Figures 104 to 111 for plots of the data). At stage one, $\%V_{O2max}$ ranged from 26-31% while $\%V_{Tmax}$ ranged from 22-36%. So, there wasn't a lot of variability in $\%V_{Tmax}$ or $\%V_{O2max}$ at the low work rates. However, at stage five, there were large differences. For work rates of 77-86% of V_{O2max}, tidal volume ranged from 61-90%. So, even when the tidal volume was expressed relative to the maximum for each subject there was a lot of variability.

The data from the subjects were pooled. A plot of the data is shown in Figure 23. From the plot, it appeared that there was a linear relationship between the variables. However, the individual plots of $\%V_{Tmax}$ versus $\%V_{O2max}$ for four subjects showed a curvilinear relationship. So, linear ($y = ax + b$), quadratic ($y = ax^2 + bx + c$), exponential ($y = ae^b$), and power ($y = ax^b$) models were fit to the pooled data. A summary of the statistics is shown in Table 13.

Table 13. Standard error ratio, bias, mean bias, and correlation coefficient for the linear, quadratic, exponential, and power models fit to the $\%V_{Tmax}$ and $\%V_{O2max}$ data.

	Linear	Quadratic	Exponential	Power
S_e/S_y	0.425	0.402	0.446	0.427
Bias	0.002	0.065	-0.797	-0.792
Mean bias	3.52E-05	0.001	-0.015	-0.015
R	0.9077	0.9077	0.8947	0.9030

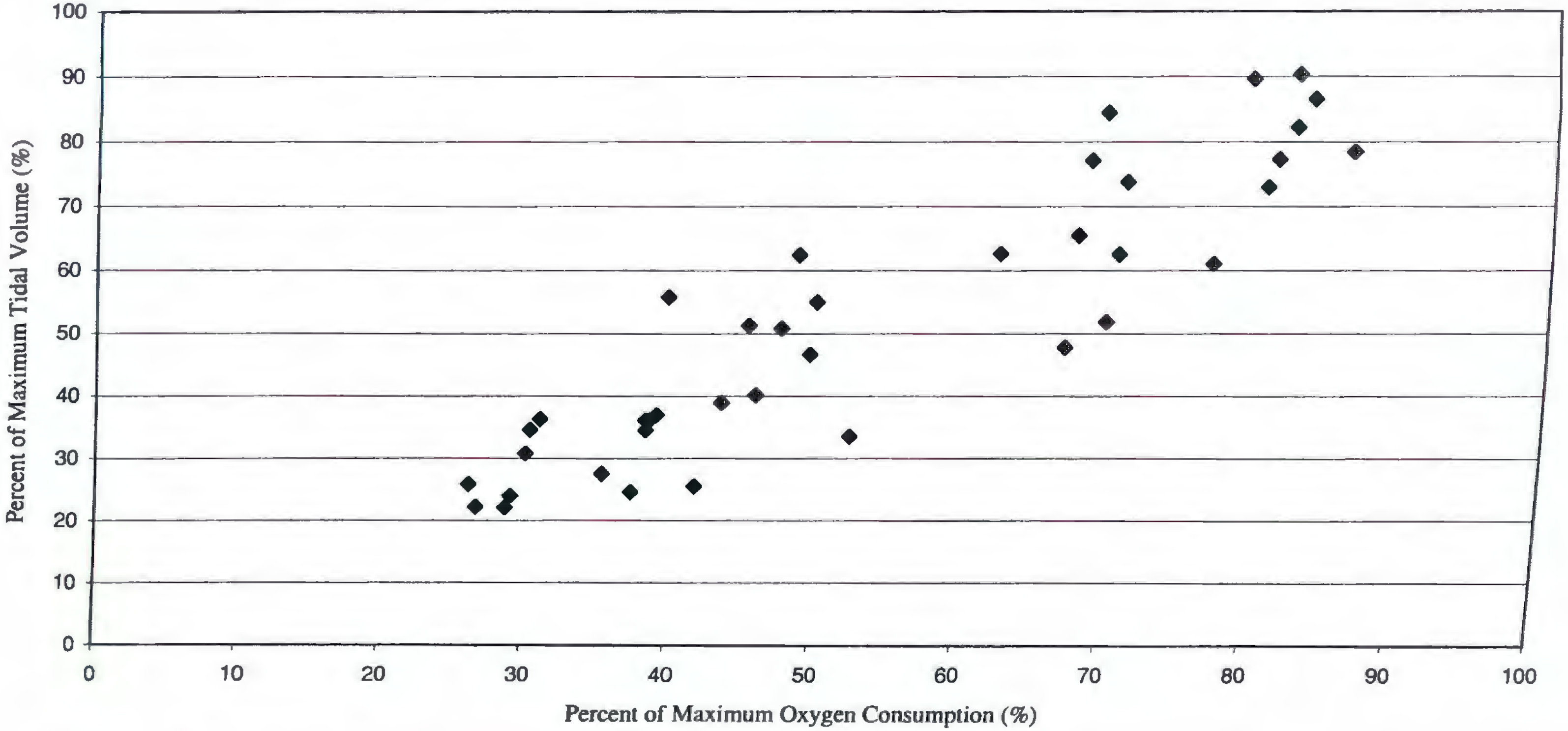

Figure 23. Data pooled from the eight subjects who completed the current study.

The standard error ratios indicated that all four models made improved predictions compared to predictions made with the mean. All four models had high correlation coefficients. The exponential and power model had biases of –0.8, indicating that they consistently under-predicted the $\%V_{Tmax}$. The linear and quadratic models had small positive biases and thus over-predicted. The fact that the mean biases for the latter two models were near zero indicated that the model bias was small compared to the average y-value ($\%V_{Tmax}$). Because of their larger biases, the exponential and power models were eliminated.

The linear and quadratic models had comparable statistics. For $100\%V_{O2max}$, the linear model predicted a tidal volume of 98% of maximum while the quadratic predicted 99% of maximum. The percent errors were evaluated. The total number of points greater than ± 20%, ± 40%, ± 50%, and ± 60% were determined. Both models had 11 points greater than ± 20%, 3 points greater than ± 40%, 2 points greater than ±50%, and no points greater than ± 60%. As the statistics and percent errors were about the same for the linear and quadratic model, there were no statistical reasons for selecting one model over the other. The linear model was selected because it was simpler. The linear model was:

$$\%V_{Tmax} = 0.9987 \cdot \%V_{O2max} - 1.6809 \qquad (72)$$

A plot of the data and the regression line are shown in Figure 24. (See Appendix B, Figures 112 to 114 for plots of the quadratic, exponential, and power models.)

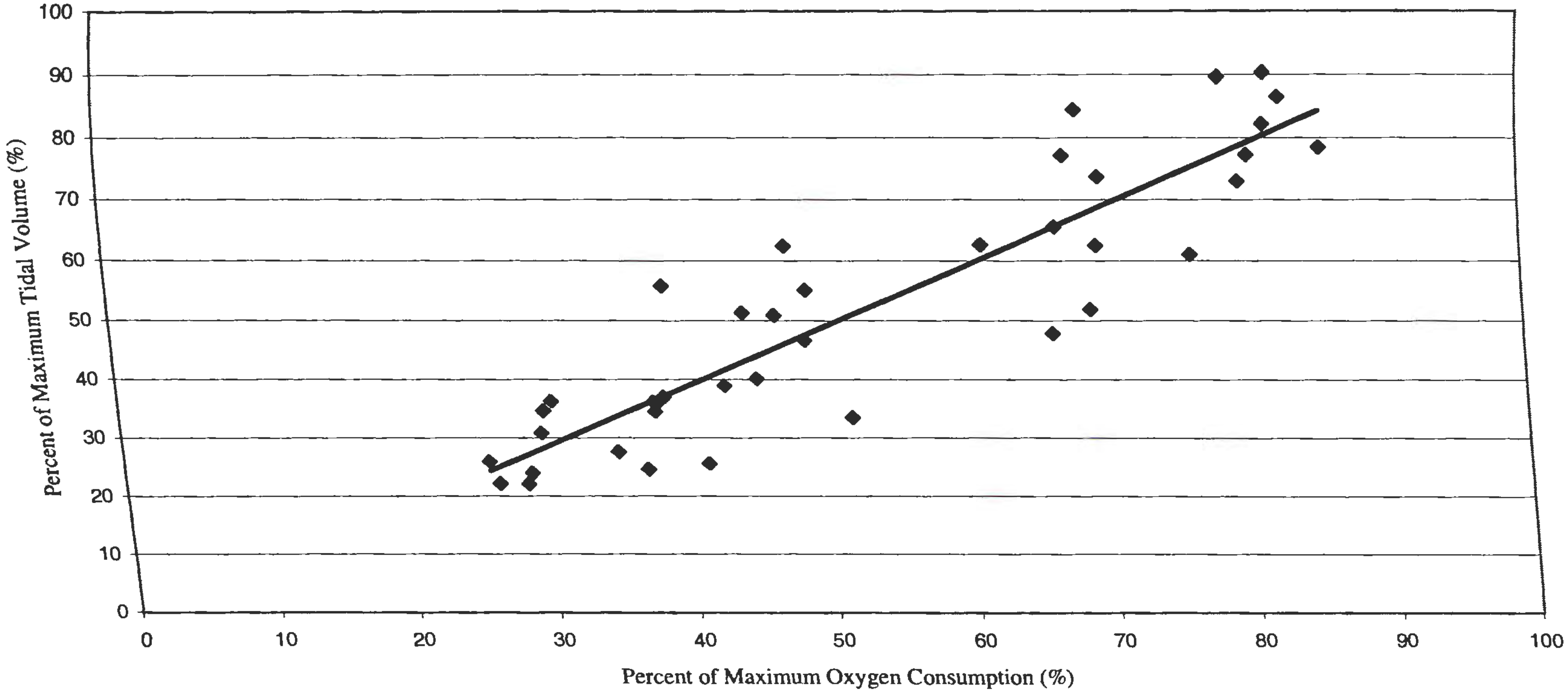

Figure 24. Linear model fit to the pooled data from the eight subjects who completed the current study.

The plot of the validation data from subjects 224 and 230 is shown with a plot of the equation in Figure 25. For these two subjects, the model consistently under-predicted the $\%V_{Tmax}$. The residuals showed that the errors were larger for lower $\%V_{O2max}$ (see Appendix B, Figure 115). This did not agree with the residuals obtained with the original data set. The percent errors ranged from –42% to 0.2%. Seven of the ten data points were within ± 20% error while nine of the ten were within ± 40%. These errors were comparable with those of the calibration data set. A larger data set is needed to truly validate equation 72. However, there are no other data available. Based on the limited data available, equation 72 makes adequate predictions of $\%V_{Tmax}$ as a function of $\%V_{O2max}$.

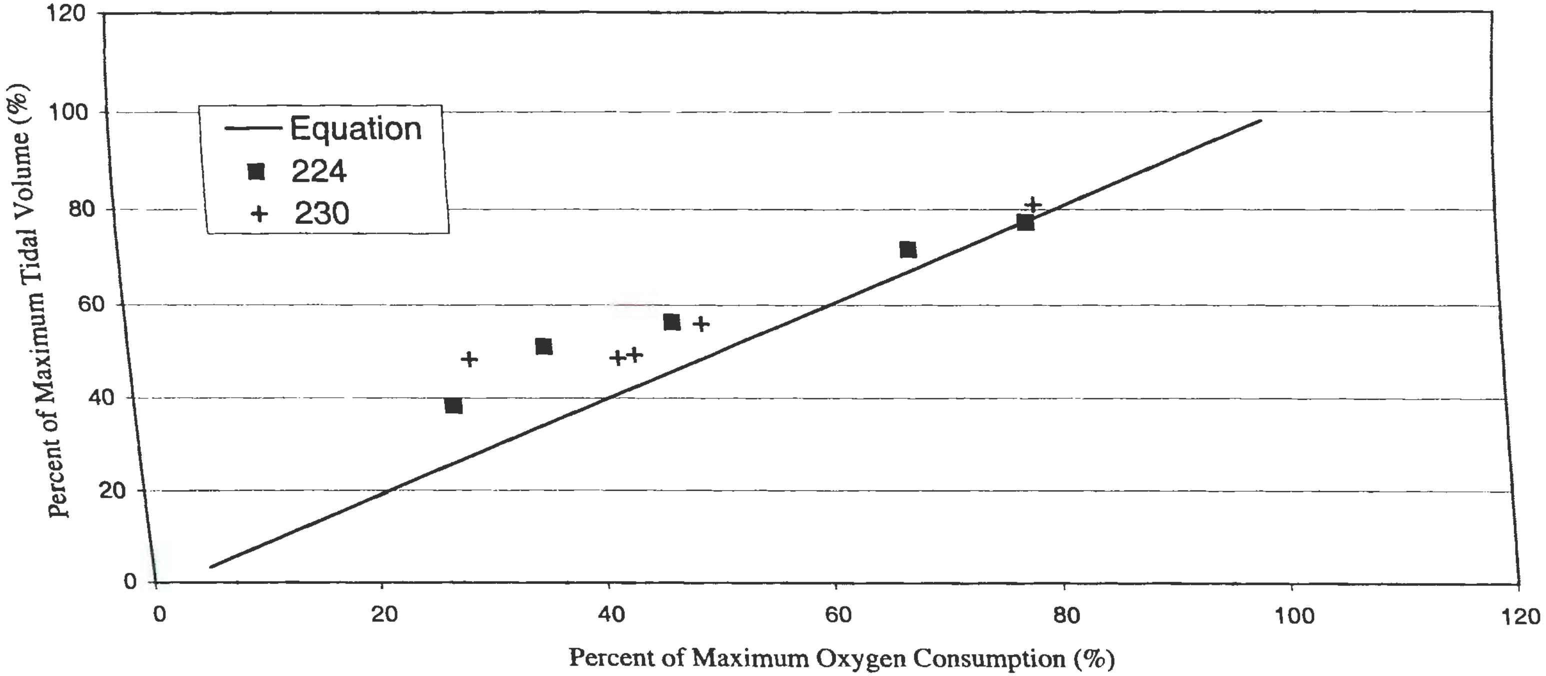

Figure 25. Validation data from subjects 224 and 230 plotted with the linear model.

Maximum Tidal Volume as a Function of Maximum Oxygen Consumption. In order to use equation 72, the maximum tidal volume (V_{Tmax}) needed to be determined. As the V_{Emax} was shown to be related linearly to V_{O2max}, it was possible that V_{Tmax} was related also to V_{O2max}. The pooled V_{Tmax} and V_{O2max} data from the three studies were sorted in ascending order by V_{O2max} so that the full range of V_{O2max} values were used for both calibration and validation. A plot of the calibration data and the linear regression equation are shown in Figure 26. The equation was:

$$V_{Tmax} = 0.3864 \cdot V_{O2max} + 0.6416 \qquad (73)$$

where: V_{Tmax}, maximum tidal volume, L

V_{O2max}, maximum oxygen consumption, L

The standard error ratio was 0.769,which indicated that an improvement in the prediction accuracy was obtained with equation 73 compared with predictions made with the mean. The correlation coefficient was 0.664. The standard error ratios for the slope and intercept coefficients were 0.266 and 0.502, respectively. McCuen (1993) had found from experience that ratios higher than 0.3 to 0.4 indicated coefficients of questionable accuracy. So, the intercept may not be accurate. The partial regression coefficient for the slope (0.663) indicated that the slope coefficient was an important predictor. The bias and mean bias were –7.4E-05 and –4.1E-05. As both were essentially zero, the model made unbiased predictions. The residuals had no apparent pattern (see Appendix B, Figure 116).

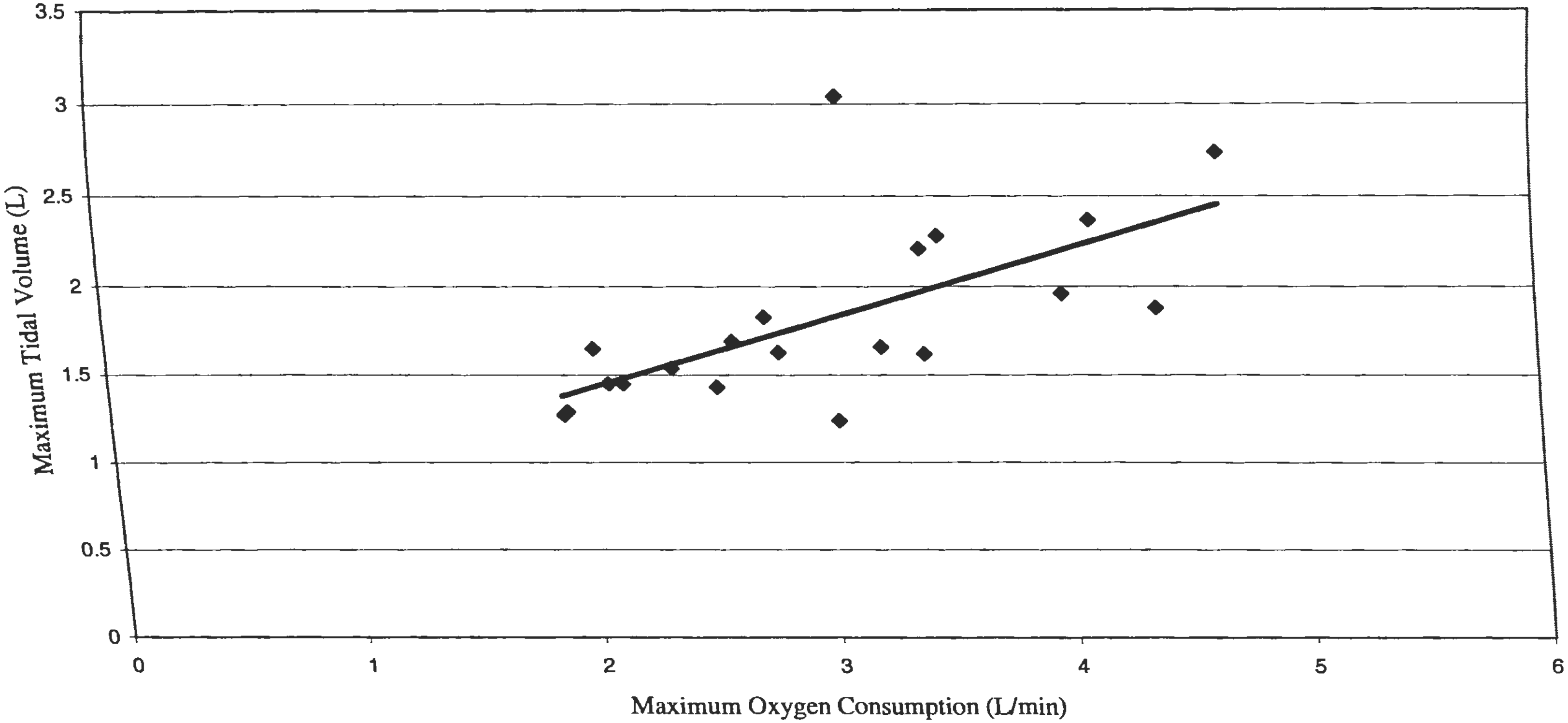

Figure 26. Linear equation fit to the calibration data.

The validation data and the linear regression equation are shown in Figure 27. The equation is:

$$V_{O2max} = 0.5 \cdot V_{Tmax} + 0.3879 \qquad (74)$$

The correlation coefficient for this equation was 0.816. The calculated t-values for the slope and intercept coefficients were 0.662 and –0.575, respectively. As both were within the critical value of ± 2.306, the null hypothesis was accepted for both. That is, the slope and intercept coefficients from equations 73 and 74 for the calibration and validation data were the same.

Summary of Tidal Volume as a Function of Oxygen Consumption. Tidal volume as a function of oxygen consumption for incremental exercise was shown for some subjects to increase linearly below the anaerobic threshold and plateau above the anaerobic threshold (Martin and Weil, 1979). Data plots for the subjects in this study showed that this relationship did not hold for steady state exercise. Four subjects exhibited curvilinear relationships while the other four each had different relationships. Part of the difference may be due to the fact that a steady state tidal volume was not always reached at low work rates even though oxygen consumption and minute ventilation were steady. Subjects were instructed to maintain breathing, stride, and arm movement as constantly as possible at the low work rates. However, many subjects reported that they would breathe shallowly and then take a deep breath. The overall minute ventilation did not change much, but the tidal volume did. This

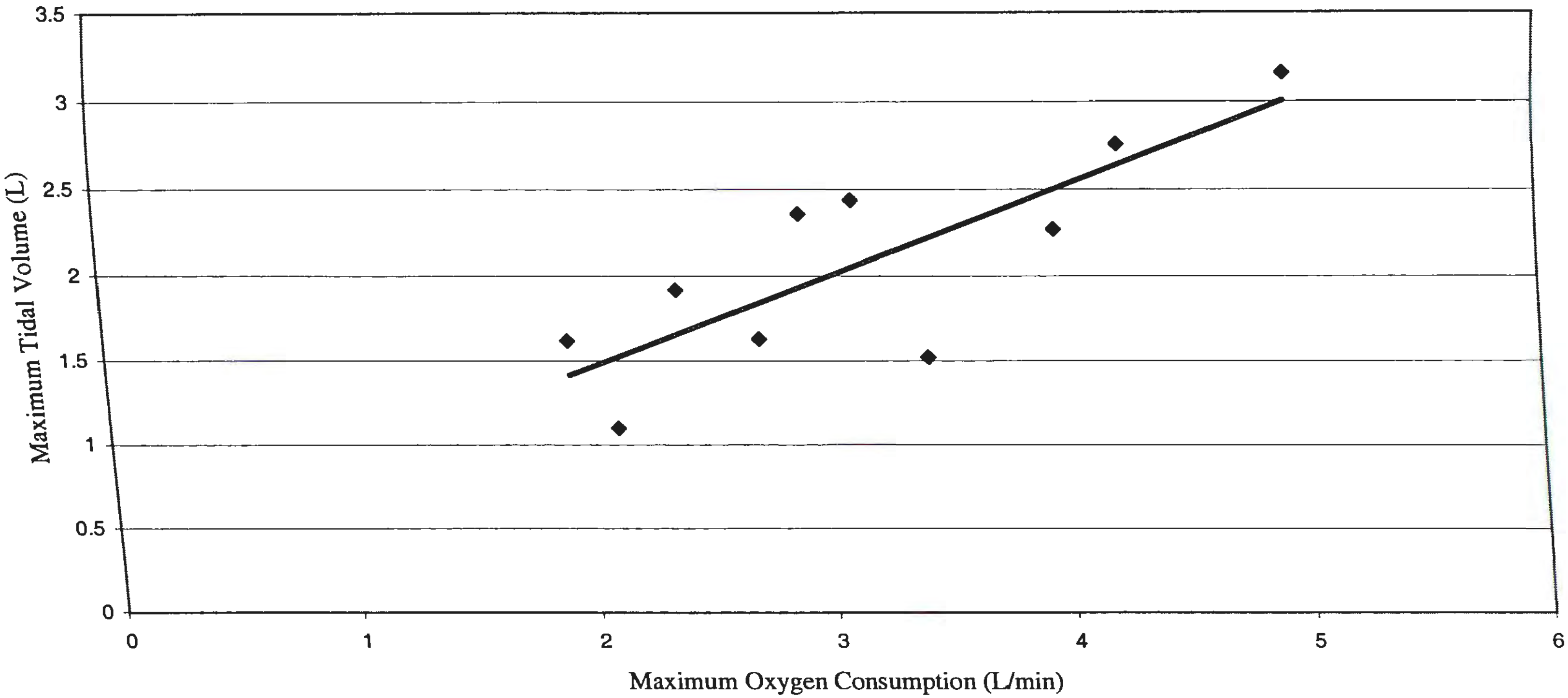

Figure 27 Linear equation fit to the validation data.

was seen in the data as a low tidal volume often followed a high tidal volume and vice-versa. At the higher work rates, subjects reported that there was less willful control of their breathing. This was evidenced by a more constant tidal volume.

Wasserman et al. (1980) showed that for long-term constant rate exercise the tidal volume would decrease slightly with time. The subjects in the current study showed variable responses with time. Some subjects had tidal volumes that decreased with time while others increased with time, varied throughout, or were near constant throughout. So, while a steady state was not achieved, the average of the tidal volumes during the time period when oxygen consumption was at steady state was used as the steady state tidal volume.

The fact that there was not a true steady state likely contributed to the differences between the shapes of the relationships. But as there was no common pattern to the tidal volume response with time across subjects and work rates, there were no other options for obtaining steady state tidal volume from the data.

Even though a curvilinear relationship was seen for four of the subjects, the best equation for the pooled data was a linear curve. While the quadratic equation did provide a comparable fit, it was rejected in favor of the simpler linear equation. The other two curvilinear functions, the exponential and power, gave biased predictions and were rejected. Overall, equation 72 made reasonable predictions.

The relationship between V_{Tmax} and V_{O2max} was not as strong as that between V_{Emax} and V_{O2max}. Even with the weaker relationship, equation 74 predicted V_{Tmax} with reasonable errors. While the intercept coefficient was of questionable accuracy, the rest of the statistics indicated that equation 74 made reasonable predictions. The validation equation was statistically the same as the calibration equation. The fact that the correlation coefficient was higher for the validation equation than for the calibration equation is another example of why small data sets should not be used with physiological data.

The Effects of Resistance on Minute Ventilation and Tidal Volume

The multiple regression equations relating minute ventilation to inhalation and exhalation resistance for each of the five stages were:

Stage one: $V_E = 0.3705 - 0.0037R_{inh} - 0.02236R_{exh}$ (75)

Stage two: $V_E = 0.4754 - 0.0018R_{inh} - 0.0206R_{exh}$ (76)

Stage three: $V_E = 0.6088 - 0.0065R_{inh} - 0.0469R_{exh}$ (77)

Stage four: $V_E = 0.9718 - 0.0156R_{inh} - 0.0846R_{exh}$ (78)

Stage five: $V_E = 1.3979 - 0.0454R_{inh} - 0.0967R_{exh}$ (79)

where: V_E, minute ventilation, L/s

R_{inh}, inhalation resistance, $cmH_2O/L/s$

R_{exh}, exhalation resistance, $cmH_2O/L/s$

The equations for tidal volume were:

Stage one: $V_T = 0.5023 + 0.0059R_{inh} + 0.1046R_{exh}$ (80)

Stage two: $$V_T = 0.6271 + 0.0092R_{inh} + 0.2080R_{exh} \tag{81}$$

Stage three: $$V_T = 0.9698 - 0.0091R_{inh} + 0.0890R_{exh} \tag{82}$$

Stage four: $$V_T = 1.4525 - 0.0027R_{inh} - 0.0024R_{exh} \tag{83}$$

Stage five: $$V_T = 1.7955 - 0.0162R_{inh} + 0.0746R_{exh} \tag{84}$$

where: V_T, tidal volume, L

R_{inh}, inhalation resistance, $cmH_2O/L/s$

R_{exh}, exhalation resistance, $cmH_2O/L/s$

Plots of the intercept and slope coefficients versus work rate for the minute ventilation and tidal volume equations are shown in Figures 28 to 31. The minute ventilation increases curvilinearly. This is to be expected from equation 69 relating minute ventilation to oxygen consumption. Similarly, the increase in tidal volume with work rate is linear as was shown in equation 72 relating tidal volume to oxygen consumption. Figure 29 shows that the resistance coefficients for minute ventilation related to work rate have a greater magnitude as work rate increases, with the exhalation resistance coefficient always having a greater magnitude than the inhalation resistance coefficient. The resistance coefficients for tidal volume shown in Figure 31 do not have a definite pattern.

The standard error ratio and correlation coefficient for the regression of minute ventilation or tidal volume on inhalation and exhalation resistance separately are shown for each of the five stages in Table 14. The bias for each model was approximately zero.

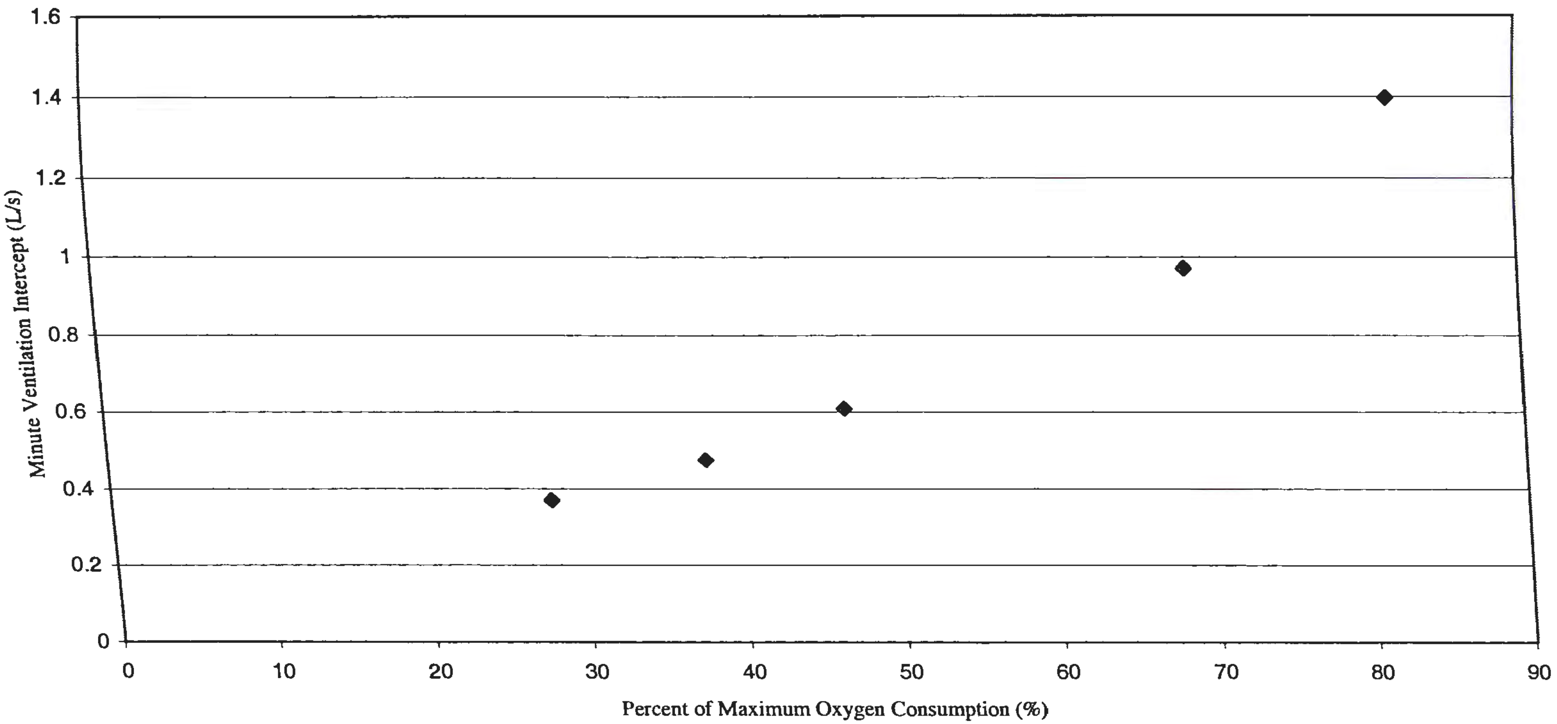

Figure 28. The intercept coefficients across work rates for the equations relating change in minute ventilation to inhalation and exhalation resistance.

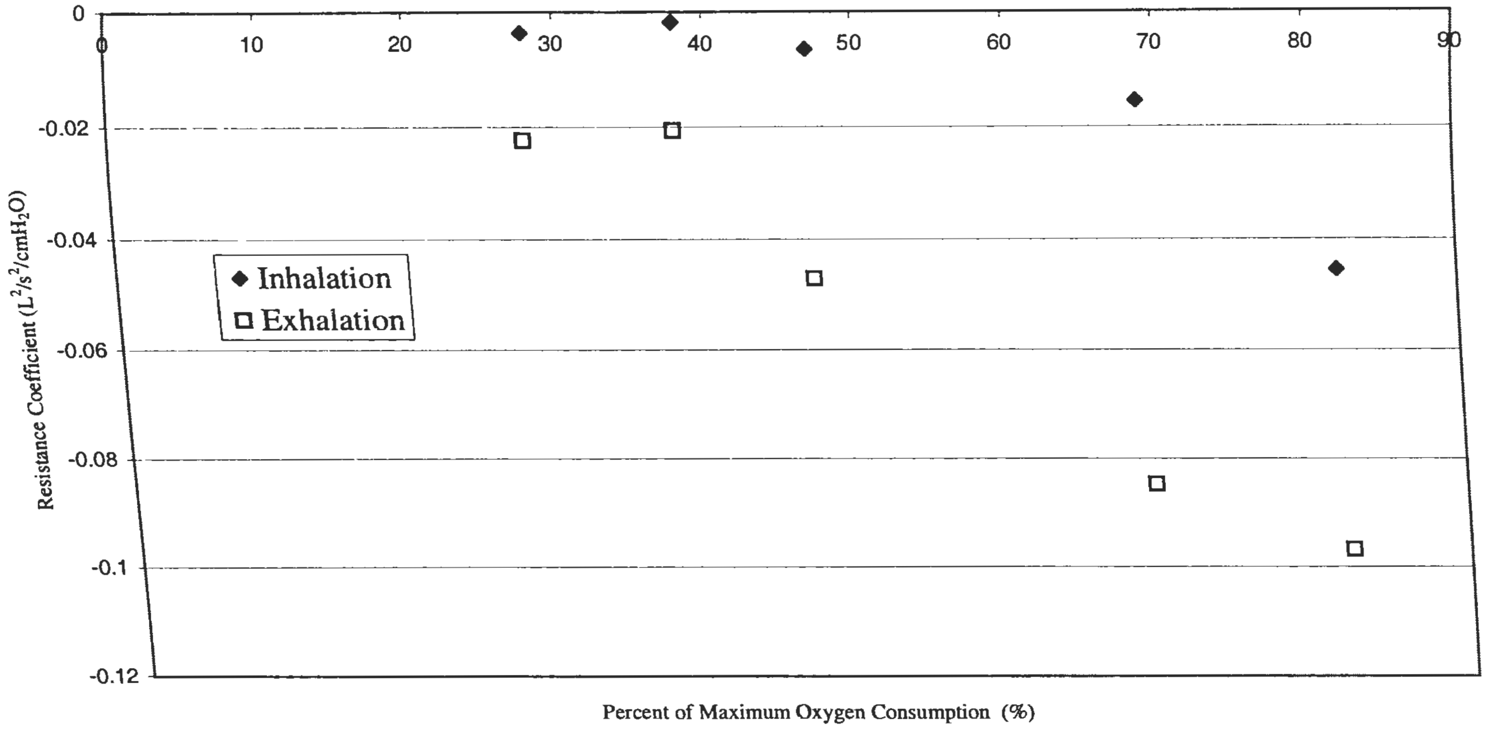

Figure 29. The resistance slope coefficients across work rates for the equations relating change in minute ventilation to inhalation and exhalation resistance.

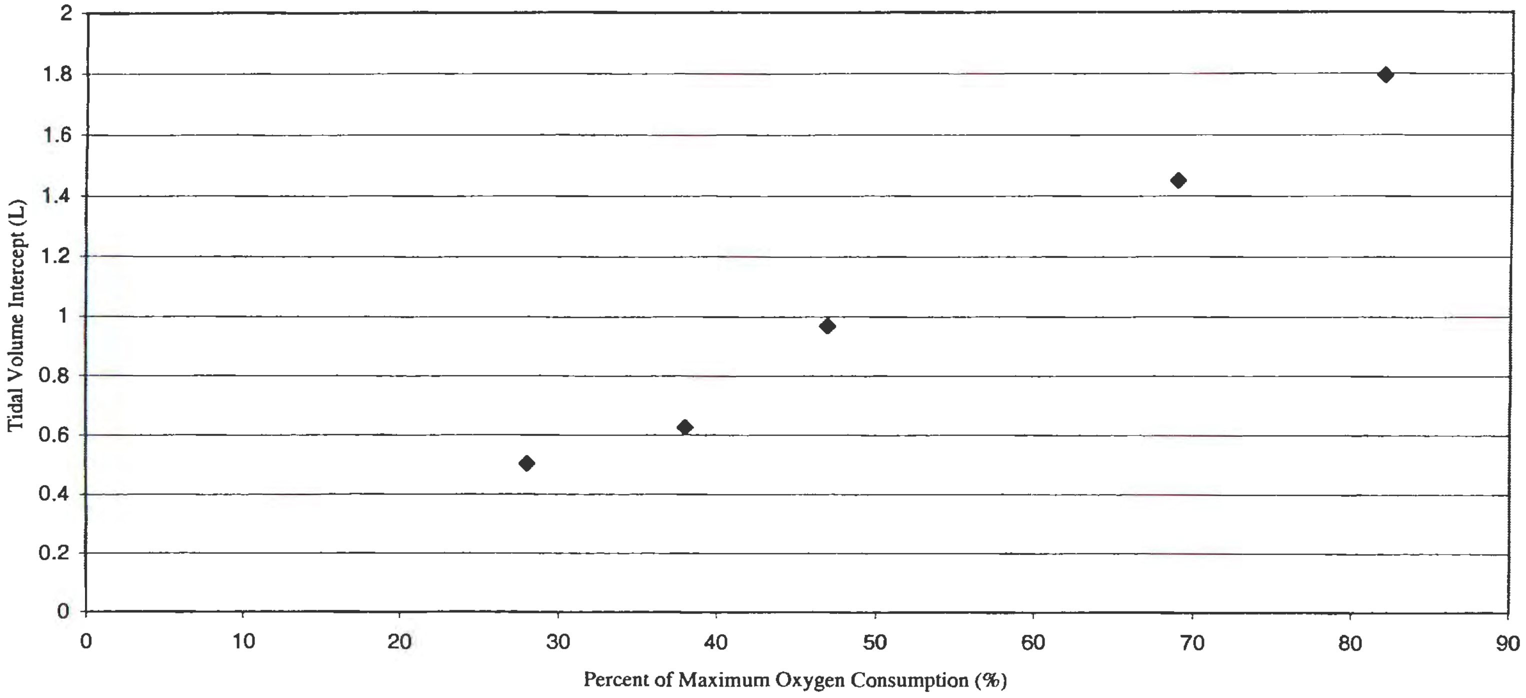

Figure 30. The intercept coefficients across work rates for the equations relating change in tidal volume to inhalation and exhalation resistance.

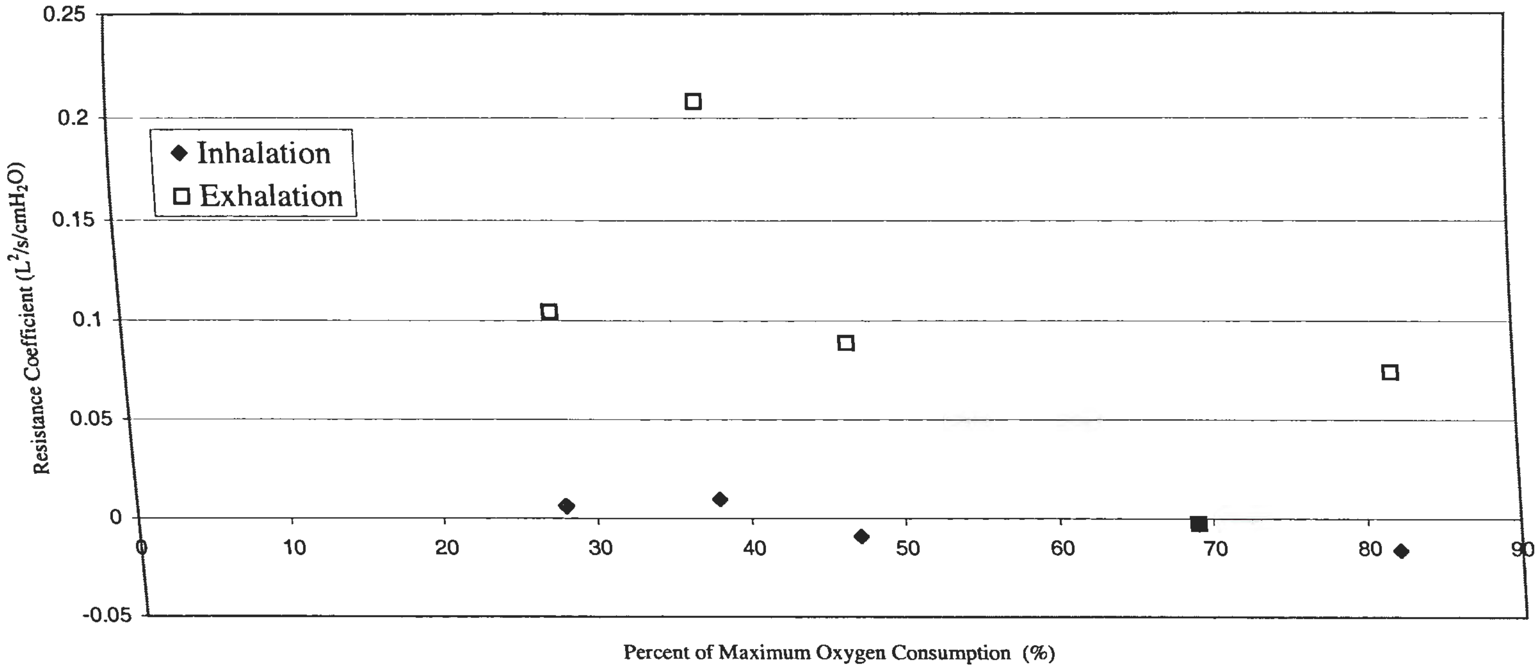

Figure 31. The resistance slope coefficients across work rates for the equations relating change in tidal volume to inhalation and exhalation resistance.

Table 14. Standard error ratio and correlation coefficient for steady-state minute ventilation and tidal volume regressed on inhalation and exhalation resistance for each of the stages.

		S_e/S_y	R
Minute Ventilation	Stage 1	0.26	0.966
	Stage 2	0.12	0.993
	Stage 3	0.35	0.937
	Stage 4	0.38	0.925
	Stage 5	0.43	0.903
Tidal Volume	Stage 1	0.89	0.456
	Stage 2	0.24	0.971
	Stage 3	0.94	0.341
	Stage 4	0.89	0.456
	Stage 5	0.02	0.9998

The standard error ratio provided an indication of the improvement in predictions made with the model compared to predictions made with the mean. A value close to one indicated that the model did not improve prediction accuracy. There were four respirator conditions and three variables being fit. With a low number of degrees of freedom, it would be expected that the correlation coefficient would be close to one.

The power of the regression equations was determined. The null hypothesis was that the correlation coefficient was zero. A standard error ratio less than 0.7 would show that a significant improvement in prediction accuracy had occurred (McCuen, 1993). The correlation coefficient corresponding to a standard error ratio of 0.7 was 0.71 (from the relationship $Se^2 = Sy^2 (1-R^2)$). Thus, the alternative hypothesis was that the correlation coefficient was greater than 0.71. For $\alpha = 0.05$ and 8 subjects ($n = 8$), the power was 0.63. As the power equals $1 - \beta$, β (the probability of a type two error) was 0.37. This means that the null hypothesis would be accepted

37% of the time when it is false. In other words, the regression is considered not significant 37% of the time when it really is.

The standard error ratios were low and correlation coefficients were high for the minute ventilation equations. These statistics indicated that there was a strong relationship between minute ventilation and resistance and that the equations provided improvements in prediction accuracy over predictions made with the means.

For the tidal volume equations, the standard errors were high and the correlation coefficients low for stages one, three, and four. These statistics indicated that the equations relating tidal volume to resistance at stages one, three, and four were not accurate. The equations for stages two and five had low standard error ratios and high correlation coefficients. Thus, equations 81 and 84 provided good predictions of tidal volume.

All of the slope coefficients in the minute ventilation equations were negative, indicating that minute ventilation decreased with increased resistance. These results agreed with those reported in the literature (Flook and Kelman, 1973; Silverman et al., 1951; Hermansen et al., 1972; Cerretelli et al., 1969; Caretti and Whitley, 1998; Johnson et al., 1999; Caretti et al., 2001). Flook and Kelman (1973) found that the slope coefficients for inhalation resistance for work rates of 35, 50, and 70% were –0.0023, -0.005, and –0.214, respectively. These work rates corresponded with stages two, three, and four in the current study. The slope coefficients in the current study (-0.0018, -0.0065, and –0.0156) were of the same order of magnitude as those found by Flook and Kelman (1973). Johnson et al. (1999) reported an inhalation slope coefficient of –0.0687 for work at 80 – 85% of V_{O2max}. The slope coefficient of inhalation from stage five in the current study was –0.0454, which is of the same magnitude. For exhalation resistance, Caretti et al. (2001) found that for work done at 80 – 85% of V_{O2max} the slope coefficient was –0.0299. The corresponding slope coefficient from the current study was –0.09674, three times that found by Caretti et al. (2001).

Caretti et al. (2001) found that the ratio of the slope coefficients of inhalation resistance to exhalation resistance was approximately three. In the current study, the exhalation resistance coefficient always had a higher value than the inhalation resistance. The ratios of exhalation to inhalation coefficients for the five stages were 6, 11, 7, 5, and 2. While Silverman et al. (1951) investigated the effects of inhalation and exhalation on minute ventilation at high work rates, the equations were not reported. So, magnitude comparisons cannot be made with this study. The reason for the discrepancy between the relative effects of inhalation and exhalation resistance is unknown. However, a small range of exhalation resistances (0.8 to 1.69 $cmH_2O/L/s$) was used in the current study. Caretti et al. (2001) used a wider range of resistances (0.27 to 27.35 $cmH_2O/L/s$). Perhaps the true effects of the exhalation resistance were not obtained with the current study.

Flook and Kelman (1973) investigated the effects of inhalation resistance on tidal volume. The authors reported that the slope coefficients of inhalation resistance were 0.0078, 0.0011, and 0.009 for exercise performed at 35, 50, and 70% of V_{O2max}. Only the first slope was significant, so there was no effect of inhalation resistance on tidal volume at work rates of 50 and 70% V_{O2max}. The inhalation resistance slope coefficient from the second stage of the current study (35 – 40% V_{O2max}) was 0.0092, which was of the same order of magnitude as the Flook and Kelman (1973) coefficient. The coefficients of inhalation and exhalation resistance for stage two were both positive, which indicated that tidal volume increased with increasing resistance. This agreed with the results of Silverman et al. (1951) and Hermansen et al. (1972) that tidal volume at low work rates increased with resistance.

There were little data on the effects of resistance on tidal volume at very low work rates. The equation for stage one of the current study was rejected because of the high standard error ratio. Silverman et al. (1951) found for subjects pedaling a bicycle ergometer with no load that tidal volume increased with resistance. This would appear to conflict with the current study that there was no effect of resistance on tidal volume at the lowest work rate. The rejection of the stage one equation may be due to the fact that the power of the current study (0.63) was lower than the conventional value of 0.8 (Ewen, 1971). With a low power, the regression may be found insignificant despite the fact that it is significant.

The fact that the equations for stage three (45 – 50% V_{O2max}) and four (65 – 70% V_{O2max}) in the current study did not provide accurate predictions indicated that there was not a significant effect of resistance on tidal volume at these two stages. These results agree with those of Flook and Kelman (1973). Silverman et al. (1951) found also that there were only small changes in tidal volume with resistance at moderate work rates.

At high work rates, Hermansen et al. (1972) and Silverman et al. (1951) found that tidal volume decreased with increased resistance. Caretti and Whitley (1998) found that tidal volume was insensitive to resistance at 80 – 85% V_{O2max}. However, the external work rate was adjusted for each respirator conditions so that the subject was working at 80 – 85% V_{O2max} with each respirator. Assuming the subjects were able to continue to increase their tidal volumes with the increased external work rates, the effect of resistance may not have been seen. Tidal volume may have increased, but the increased resistance could have offset the tidal volume increases.

The slope coefficient of the exhalation resistance for stage five was positive, indicating that the exhalation resistance increased the tidal volume. While both Silverman et al. (1951) and Hermansen et al. (1972) found that tidal volume decreased at high work rates, the individual contributions of inhalation and exhalation resistance were not quantified. For stage five in the current study, the percent changes in tidal volume compared to the lowest condition were 3.5, 2.6, and –3.5%. So, the tidal volume increased and decreased. If the percent changes were instead compared to the first respirator condition, the changes were –1 and –7%. Both Silverman et al. (1951) and Hermansen et al. (1972) used only two resistances. As the effects of resistance on tidal volume in the current study depended on which resistances were compared, perhaps the true effect of resistance on tidal volume was not seen in the other two studies.

Change in Minute Ventilation with Dead Space

The minute ventilation and dead volume data are presented in Table 15. The dead volumes shown in the table differ from the actual values used by Stannard and

Russ (1948) because the table values were read off their Figure 1, a plot of data points showing change in minute ventilation versus dead volume.

Table 15. Changes in minute ventilation (L/s) with external dead volume (L) at rest and during light and heavy exercise. The rest and light exercise data are from Stannard and Russ (1948) while the 80 – 85% V_{O2max} data are from Johnson et al. (2000).

V_D (L)	ΔV_E (L/s)	Exercise Level
0.249	0.0348	Rest
0.351	0.0546	Rest
0.351	0.0565	Rest
0.419	0.0621	Rest
0.543	0.0800	Rest
0.645	0.1073	Rest
0.249	0.0019	Light Exercise
0.351	0.0169	Light Exercise
0.419	0.0358	Light Exercise
0.543	0.0621	Light Exercise
0.645	0.0753	Light Exercise
0.288	0	80 – 85% V_{O2max}
0.381	0	80 – 85% V_{O2max}
0.445	0	80 – 85% V_{O2max}
0.645	0	80 – 85% V_{O2max}
1.162	0	80 – 85% V_{O2max}

Figure 32 shows a plot of the resting data and the regression line. The equation that resulted from the regression was:

$$\Delta V_E = 0.170432 V_D - 0.00681 \tag{85}$$

where: V_D, added external dead volume, L

ΔV_E, change in minute ventilation, L/s

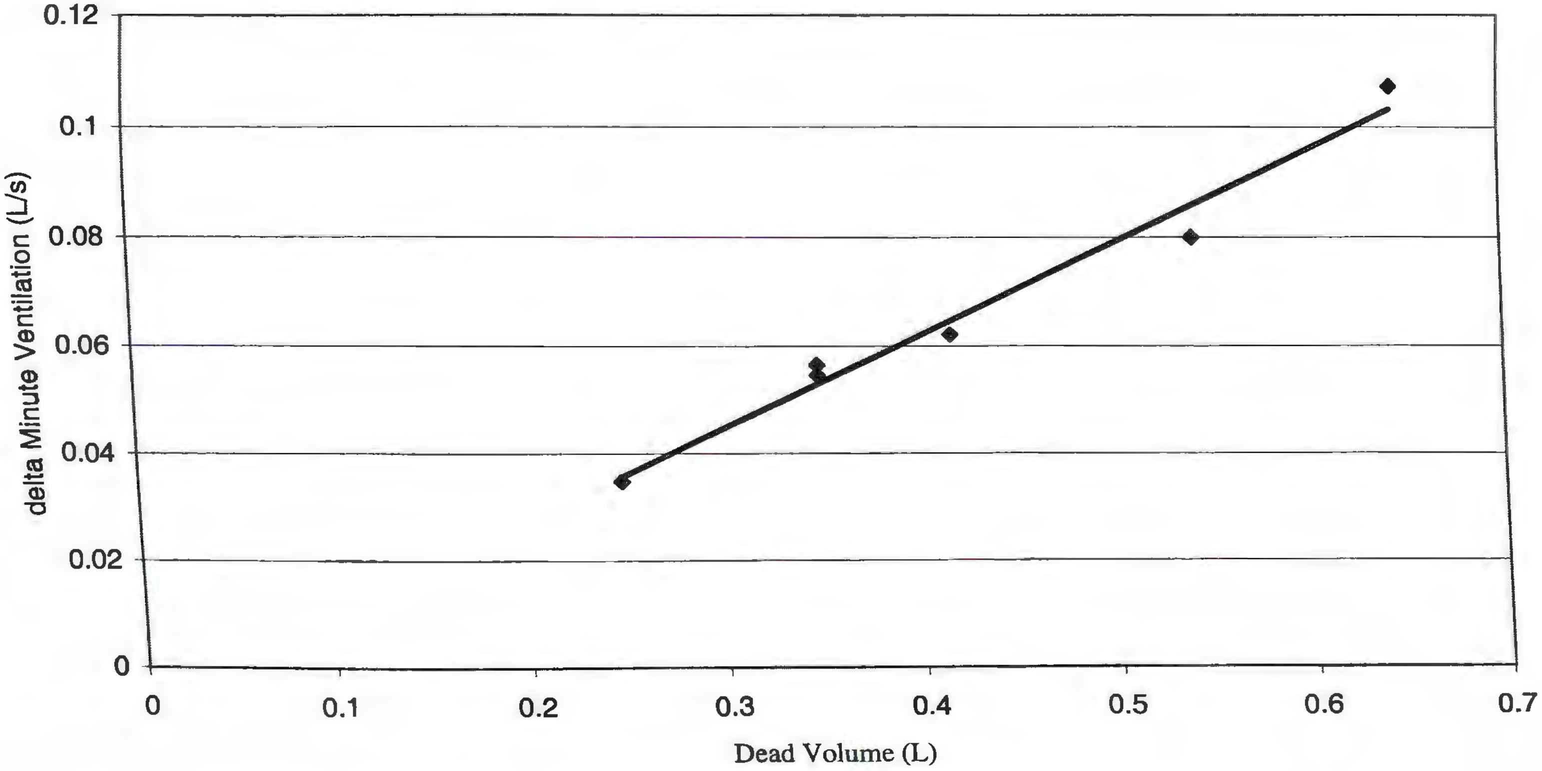

Figure 32. The change in minute ventilation with added dead volume for resting subjects.

The correlation coefficient was 0.984, which indicated there was a strong correlation between the change in minute ventilation and the dead volume. The model predictions were much better than predictions made with the mean as evidenced by the standard error ratio of 0.17. The bias and mean bias were both zero so the model did not consistently over- or under-predict. There was no pattern to the residuals (see Appendix B, Figure 117). The percent errors ranged from –6% to 7%. Thus, equation 85 accurately predicted the change in minute ventilation due to added dead space for resting subjects.

The plot of the light exercise data and the regression line are shown in Figure 33. The relationship between the change in minute ventilation and the dead space was:

$$\Delta V_E = 0.19414 V_D - 0.04733 \qquad (86)$$

A correlation coefficient of 0.9944 indicated that there was a strong relationship between the variables. The standard error of 0.12 showed that the model predictions were an improvement over predictions made with the mean. The bias and mean bias of zero indicated that the model neither consistently over- nor under-predicted. There was no pattern to the residuals (see Appendix B, Figure 118). The percentage errors were –45%, 23%, -5%, -6%, and 4%. Overall, the model made accurate predictions of the change in minute ventilation based on dead space for subjects performing light exercise.

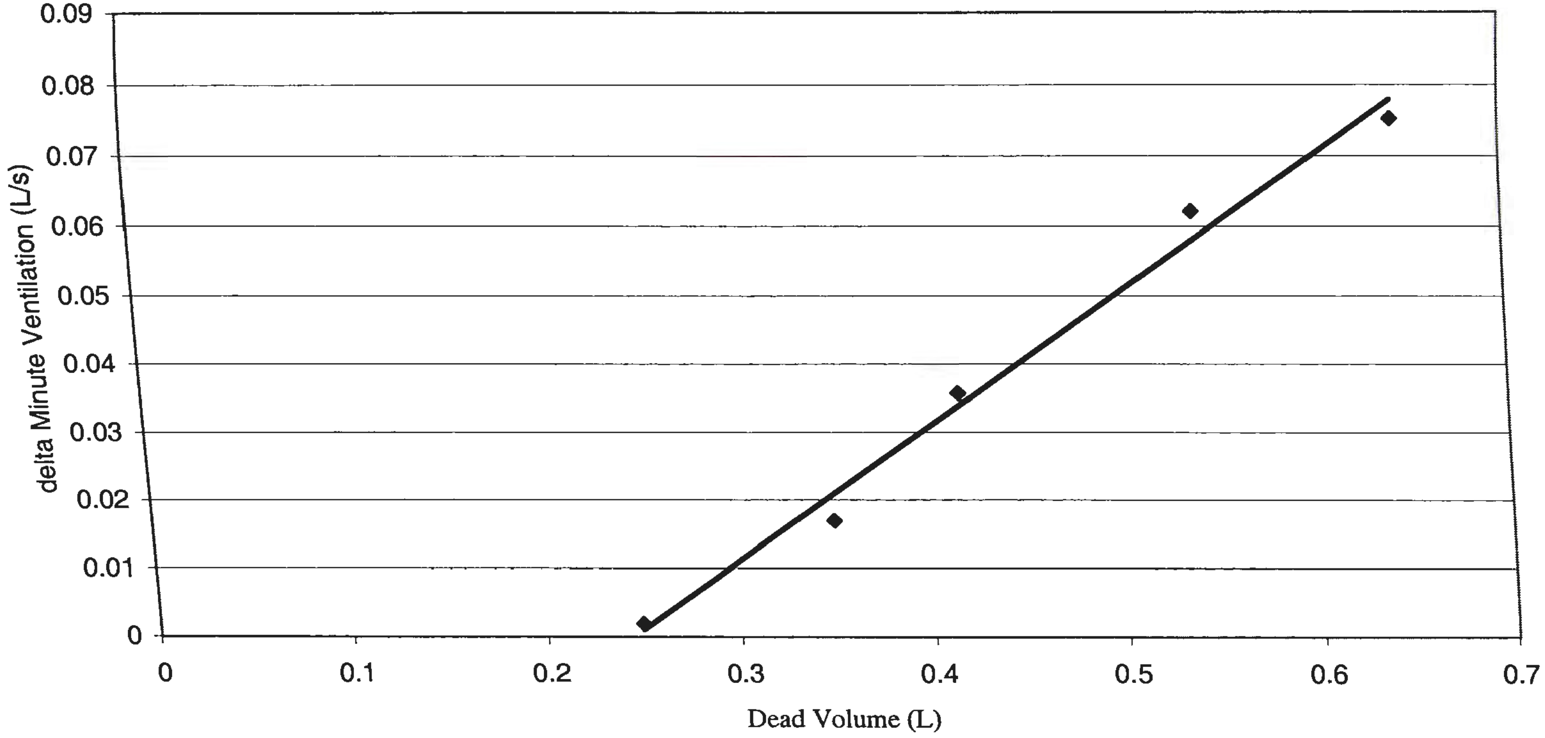

Figure 33. The change in minute ventilation with added dead volume for lightly exercising subjects.

Stannard and Russ (1948) noted that the slopes of the two equations were similar and that there appeared to be a 2 L/min or 0.033 L/s difference between the corresponding minute ventilations. The t-test of the slope and intercept was used to test this observation statistically. The calculated t values for the slope and intercept were 0.13 and -8.47, respectively while the critical t value was 3.182. So, the null hypothesis was accepted for the slope coefficient but not for the intercept coefficient. Thus, the slope coefficients of equations 85 and 86 were the same while the intercept coefficients were different.

The average difference between the predictions made with equations 85 and 86 were 0.0301 L/s, or 1.80 L/min, slightly less than the 2.0 L/min observed by Stannard and Russ (1948). The light exercise involved work rates that doubled the resting oxygen consumption. Actual data were not provided. If the resting oxygen consumption was assumed to be 0.45 L/min and the V_{O2max} were 3 L/min, the resting oxygen consumption was 15% of V_{O2max} while the light exercise was 30% V_{O2max}. These resting and maximal oxygen consumptions were typical values obtained from the current study. If it is further assumed that the minute ventilation decreases 1.8 L/min for every 15% increment in $\%V_{O2max}$, an equation can be developed that relates the change in minute ventilation to both dead volume and work intensity. The 1.8 L/min decrement could be subtracted from the original resting equation. This would yield:

$$\Delta V_E = 0.170432V_D - 0.00681 - \frac{(\%V_{O2max} - 0.15)}{0.15} \cdot \left(\frac{1.8}{60}\right) \qquad (87)$$

The third term decrements the minute ventilation 1.8 L/min or 0.0301 L/s (1.8/60) for every 15% increment in work intensity. For a work intensity of 15%, equation 87 reduces to equation 85.

Equation 87 was applied to the light exercise data. The residuals indicated that the model over-predicted for low dead volumes and under-predicted for higher dead volumes (see Appendix B, Figure 119). With only five points, it was difficult to tell whether there was truly a pattern to the residuals. The percentage errors were 194, 35, -4, -10 and –3%. The 194% error occurred for the 0.249 L dead volume. The actual change in minute ventilation was very small, 0.0019 L/s or 0.1129 L/min. The predicted value was 0.33 L/min, so the error is really just 0.22 L/min. So, equation 87 does make accurate predictions for light exercise.

For heavy exercise, Johnson et al. (2000) reported no change in minute ventilation with external dead space. Equation 87 predicted negative changes in minute ventilation for work rates of 80% V_{O2max}. If the results were forced to zero, equation 87 would be accurate.

For equations 85 and 86, change in minute ventilation were predicted for no added dead volume. The data on which these two equations were based only looked at dead volumes between 250 and 645 mL. Generally, models should not be used beyond the data ranges for which they were developed (McCuen, 1993). However, data were not available at lower dead volumes for subjects at rest or during light exercise. The overall model of the pulmonary effects of respirator wear will include a no mask condition, and hence a condition with no added dead volume. Equations 85 and 86 will be used for that model. If the equation predicts a negative minute ventilation, the change in minute ventilation is forced to zero. What this says is that as work rate increases, a given dead volume causes a smaller change in minute ventilation. This agrees with the results obtained by Stannard and Russ (1948) for resting and lightly exercising subjects. Their Figure 1 and equation 86 showed that for lightly exercising subjects, dead volumes below approximately 250 mL would not change minute ventilation. If their graph, or equation 86, were extrapolated below 250 mL, negative changes would result. Forcing the change to zero simply says that the given dead space has no effect on minute ventilation at that work rate.

So, predictions of the change in minute ventilation due to external dead space at different work rates could be determined using equation 87. If the equation predicted negative changes in minute ventilation, the change was forced to zero.

The effects of dead volume on minute ventilation for subjects exercising at moderate work rates needs to be quantified. The literature had many articles on the effects of dead space, but there were problems with the reported results. Some researchers only reported subjective results (Shimozaki et al., 1988) or used subject-selected work rates (Harber et al., 1982) or only used one combination of resistance and dead space (Harber et al., 1984; Harber et al., 1988; Harber et al., 1990), preventing comparisons from being made. Ward and Whipp (1980) did perform a study in which three subjects exercised with dead volumes of 0.1 to 1.0 L. Minute ventilation was reported versus absolute carbon dioxide production for one subject. The linear relationship between minute ventilation and carbon dioxide production shifted upwards and to the left for increases in dead volume. Data points were not recorded at the same V_{CO_2}, so changes in minute ventilation could not be quantified.

Many assumptions were made in developing equation 87. Errors in predicting the change in minute ventilation at moderate intensity exercise were likely. The work intensity was assumed. It was assumed also that similar decreases in minute ventilation occurred as exercise intensity increased as was reported in Stannard and Russ (1948) for the rest and light intensity exercise. However, no additional data were available. More studies and more testing of equation 87 are needed.

Change in Tidal Volume with Dead Space

The tidal volume and dead volume data are shown in Table 16.

Table 16. Changes in tidal volume (L) with external dead volume (L) at rest and during light and heavy exercise. The rest and light exercise data are from Stannard and Russ (1948) while the 80 – 85% V_{O2max} data are from Johnson et al. (2000).

V_D (L)	ΔV_T (L)	Exercise Level
0.25	0.132	Rest
0.35	0.209	Rest
0.35	0.163	Rest
0.42	0.144	Rest
0.55	0.347	Rest
0.640	0.410	Rest
0.25	0.006	Light Exercise
0.35	0.111	Light Exercise
0.42	0.114	Light Exercise
0.55	0.310	Light Exercise
0.640	0.386	Light Exercise
0.288	0	80 – 85% V_{O2max}
0.381	0	80 – 85% V_{O2max}
0.445	0	80 – 85% V_{O2max}
0.645	0	80 – 85% V_{O2max}
1.162	0	80 – 85% V_{O2max}

The equation obtained from regression on the resting data was:

$$\Delta V_T = 0.7468 V_D - 0.08445 \tag{88}$$

where: V_D, added external dead volume, L

ΔV_T, change in tidal volume, L

The data and the regression line are shown in Figure 34. The correlation coefficient was 0.9229, which indicated that there was a high correlation between the dead

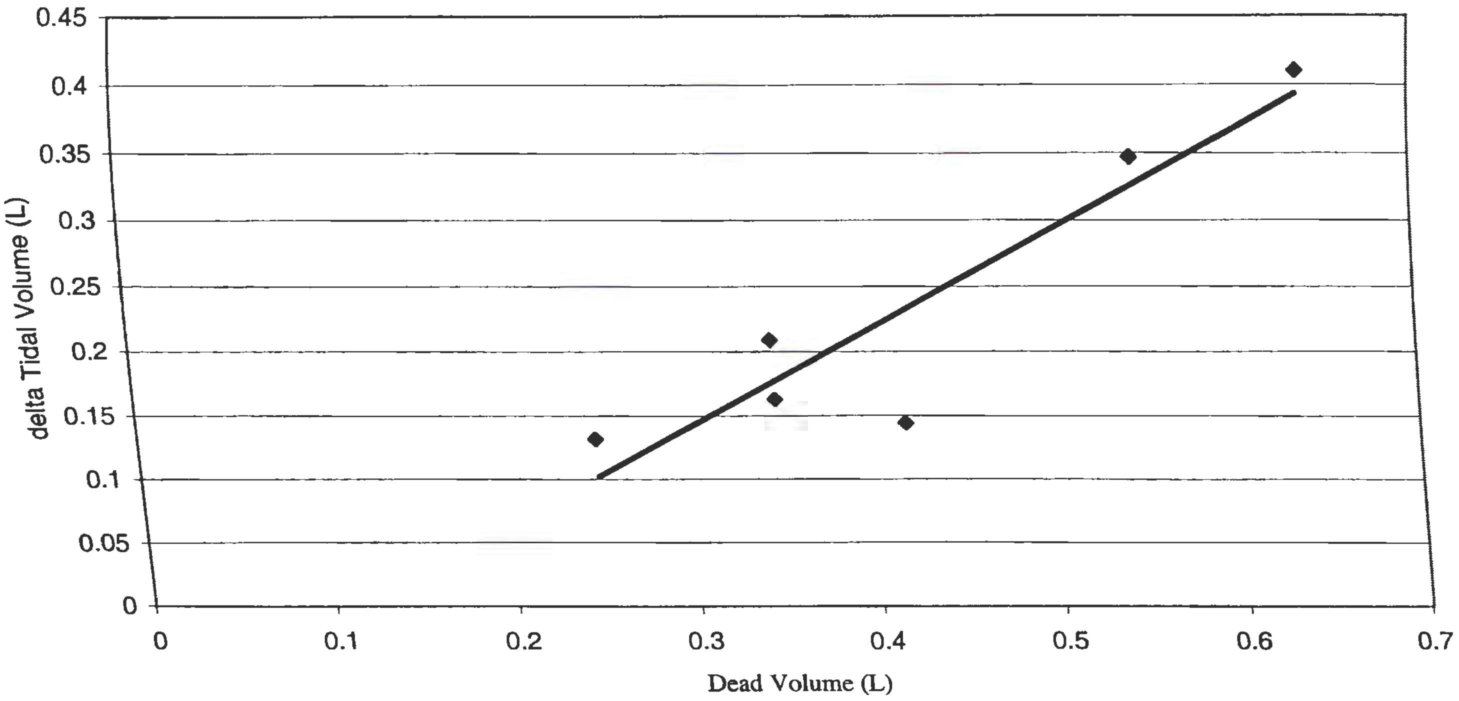

Figure 34. The change in tidal volume with added dead volume for resting subjects.

volume and the change in resting tidal volume. The model and relative bias were zero, indicating that the model neither consistently under- or over-predicted. The standard error ratio of 0.43 indicated that equation 88 made better predictions of tidal volume than the mean tidal volume. There might be a pattern to the residuals (see Appendix B, Figure 120). The model may under-predict for low and high values of dead volume and may over-predict for moderate values. However, at a dead volume of 0.35 L, the model over-predicts one point and under-predicts the other. With only six data points, a pattern to the residuals was difficult to detect. The percentage error ranged from –23% to 59%. Four of the points were within ± 20%. The statistics indicated that equation 88 made adequate predictions of the change in tidal volume with dead volume for resting subjects. However, due to the variability seen in physiological data, any equation obtained from only six data points should be used with caution.

For light exercise, the relationship between the change in tidal volume and dead volume was:

$$\Delta V_T = 0.9933 V_D - 0.2537 \tag{89}$$

Figure 35 showed the data and regression line. The correlation coefficient of 0.9837 indicated that there was a very strong relationship between tidal volume and dead volume. The model neither consistently over- nor under-predicted as indicated by the zero model and relative biases. The standard error ratio was 0.2076. This indicated that equation 89 made much better predictions of the change in tidal volume

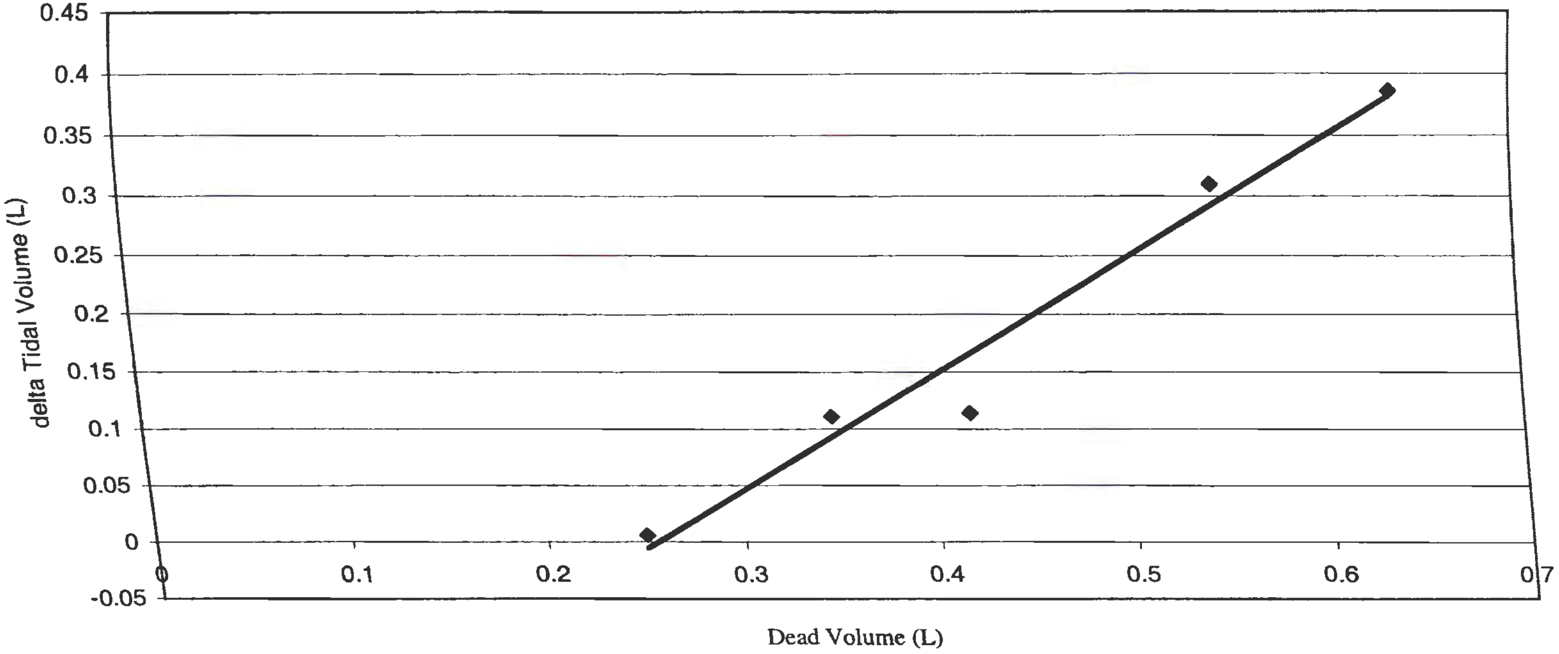

Figure 34. The change in tidal volume with added dead volume for lightly exercising subjects.

compared to using the mean change in tidal volume. The residuals indicated that the model under-predicted the change in tidal volume with low and high dead volumes and over-predicted at moderate dead volumes (see Appendix B, Figure 121). Again, with only five data points, the actual pattern to the residuals was difficult to assess. The percent errors ranged from –189% to 43%. However, the point that generated the –189% error had a negative predicted tidal volume change. The actual value was 0.006 L and essentially represented no change in tidal volume with a dead volume of 0.25 L during light exercise. Three of the five points were within 15% of the actual values. The statistics indicated that the model made accurate predictions of the change in tidal volume with dead volume except at low dead volumes. If negative changes were predicted, the change was forced to be zero.

Stannard and Russ (1948) reported that the exercise intensity was selected to double the resting oxygen consumption. Maximal oxygen consumption and resting oxygen consumption values were not reported. Assuming a resting oxygen consumption of 0.45 L/min, doubling the resting value would yield 0.9 L/min. The resting oxygen consumption expressed as %V_{O2max} would be 18% while the light exercise would be 36% assuming a V_{O2max} of 2.5 L/min. If the V_{O2max} were 3.0 L/min instead, the resting and light exercise would be 15% and 30% respectively. The resting and V_{O2max} values were typical values from the current study. So, the resting and light exercise values from Stannard and Russ (1948) were assumed to occur at 15% and 30% of V_{O2max}.

The multiple regression equation fit to the data in Table 16 was:

$$\Delta V_T = 0.1950 + 0.2517 V_D - \frac{0.4256\% V_{O2max}}{100} \qquad (90)$$

The correlation coefficient of 0.79 indicated that there was a strong relationship between the change in tidal volume and dead volume and $\%V_{O2max}$. The model and mean bias were zero which indicated that the model did not consistently over- or under- predict. The standard error ratio was 0.6583. Thus, predictions made with the model were better than predictions made with the mean. There was no pattern to the residuals (see Appendix B, Figure 122). The percentage errors ranged from –64% to 40%. Thus, equation 90 made acceptable predictions of the change in tidal volume resulting from added dead volume.

For high work rates and low dead volumes, the multiple regression equation predicted negative changes in tidal volume. This contrasted to the zero changes in tidal volume with dead volume found by Johnson et al. (2000) and Caretti and Whitley (1998) for work rates of 80-85% V_{O2max}. This can be corrected with the multiple regression equation by setting all predicted negative changes to zero. For resting and lightly exercising subjects, equations 88 and 89 had smaller errors than equation 90, the multiple regression equation. For this reason, equations 88 and 89 were used for predicting the changes in tidal volume with dead volume for resting or lightly exercising subjects (30% V_{O2max}). All predicted negative changes were forced to zero. Additionally, for a 0.25 L dead volume at 30% V_{O2max}, the change in tidal volume was close to zero. For all work rates greater than 30% V_{O2max}, the effect of dead volumes of 0.25 L or smaller were assumed to be zero. It is possible that as work intensity increases, the amount of dead space that does not affect tidal volume will increase. For example, it may be that at 50% V_{O2max}, dead volumes of 0.3 L and lower have no effect on tidal volume. Because there were no data to support this contention, such an effect was not included in the model.

There are a number of studies that have been conducted on the effects of dead volume at moderate intensity exercise, but these studies did not provide useful data for this model. Harber et al. (1982) had subjects working at moderate intensities and reported that the dead volume caused a decrease in tidal volume. However, subjects selected their own work rates so that the rate was consistent with long-term work. So, the effect can't be quantified because the subjects were not all working at the same absolute or relative work rate. Additionally, individual subject data was not reported. Other studies conducted by the same group of authors (Harber et al., 1988; Harber et al., 1984; Harber et al., 1990) looked at the effects of one load that consisted of an inhalation resistance and a dead volume. While adding dead space usually adds a resistance as well, including more conditions would have made comparisons possible. One study by these authors (Shimozaki et al., 1988) did look at combinations of inspiratory and expiratory loads and dead volume. Unfortunately, only subjective responses were reported. Ward and Whipp (1980) studied the effects of dead spaces of 0.1 to 1.0 L on three subjects during exercise. The effects of the dead space on tidal volume were not reported.

More information on the effects of dead volume on tidal volume during light and moderate intensity exercise is needed. The multiple regression equation based on the Stannard and Russ (1948) data assumed work rates for the reported data. Clearly this was not as accurate as using actual work rates, but these were not reported. Equation 90 is based on a number of assumptions and is likely to make errors in predictions. However, no other information on the separate effect of dead volume on tidal volume was available to include in the calibration or to perform a validation.

Oxygen Consumption as a Function of Minute Ventilation

Regression usually assumes that there is no variability in the x-variable; all the variability is in the y-variable. Therefore, an equation obtained from regressing a dependent variable on an independent variable should not be used to solve for the independent variable unless the correlation coefficient equals one (McCuen, 1993). So, equation 69 (from minute ventilation as a function of oxygen consumption) could not be solved for oxygen consumption based on minute ventilation.

The plot of the data and the regression line are shown in Figure 36. The equation of the line was:

$$V_{O2} = 0.0340V_E + 0.4322 \tag{91}$$

where: V_E, minute ventilation, L/min

V_{O2}, oxygen consumption, L/min

The correlation coefficient, standard error ratio of the model, standard error ratio of the slope and intercept coefficients, and the model bias were 0.928, 0.378, 0.065, and 0.251, respectively. The correlation coefficient indicated that there was a very strong

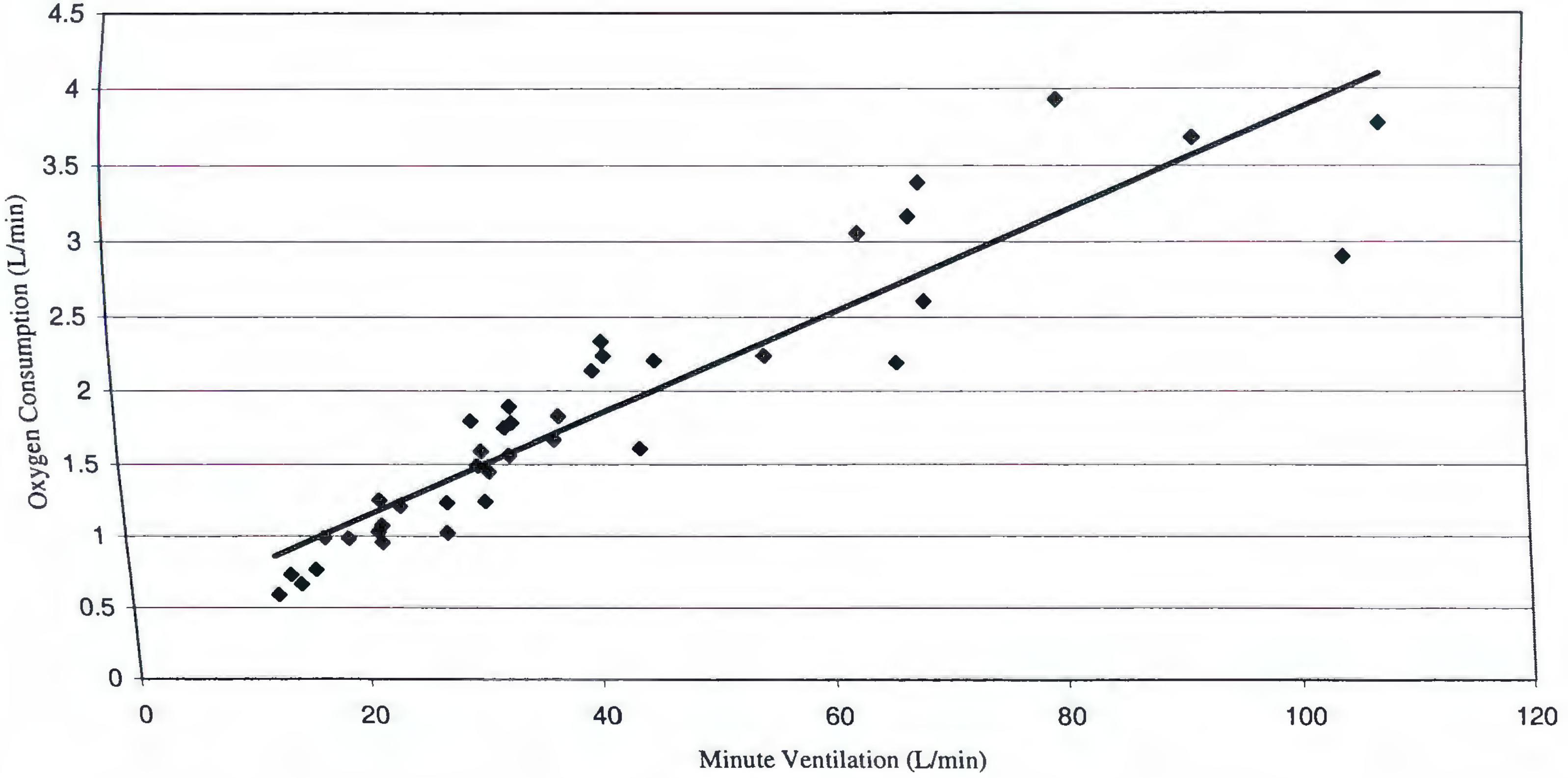

Figure 36. Oxygen consumption and minute ventilation from the levels determination session. Shown is the best fit line.

relationship between the two variables. The standard error ratio for the model was an indicator of the improvement in prediction accuracy for predictions made with the model compared to those made with the mean. The closer the number is to zero, the greater the improvement. So, a large improvement in prediction accuracy was achieved using the model. Standard error ratios of coefficients indicate the importance of that coefficient. Values close to zero indicated important predictors. Both the slope and intercept coefficients were important predictors. The model bias was zero, which indicated that the model neither under- nor over-predicted consistently. There was no pattern to the residuals (see Appendix B, Figure 123). The percent errors ranged from –20% to 46% with 90% of the errors less than ± 30%. Eighty-seven percent of the errors were within ± 25%. Overall, the statistics indicated that the model made accurate, unbiased predictions.

The validation data are plotted in Figure 37. The percent errors ranged from –9 to 16% with 90% of the error within ± 10%. These errors were smaller than those obtained with the calibration data.

Oxygen Consumption as a Function of Tidal Volume

Regression usually assumes that all of the variability is in the x-variable and none is in the y-variable. For this reason, equations developed by regressing y on x should not be used to solve for x unless the correlation coefficient is one (McCuen, 1993). Therefore, equation 67 (from tidal volume as a function of oxygen consumption) was not solved for the oxygen consumption.

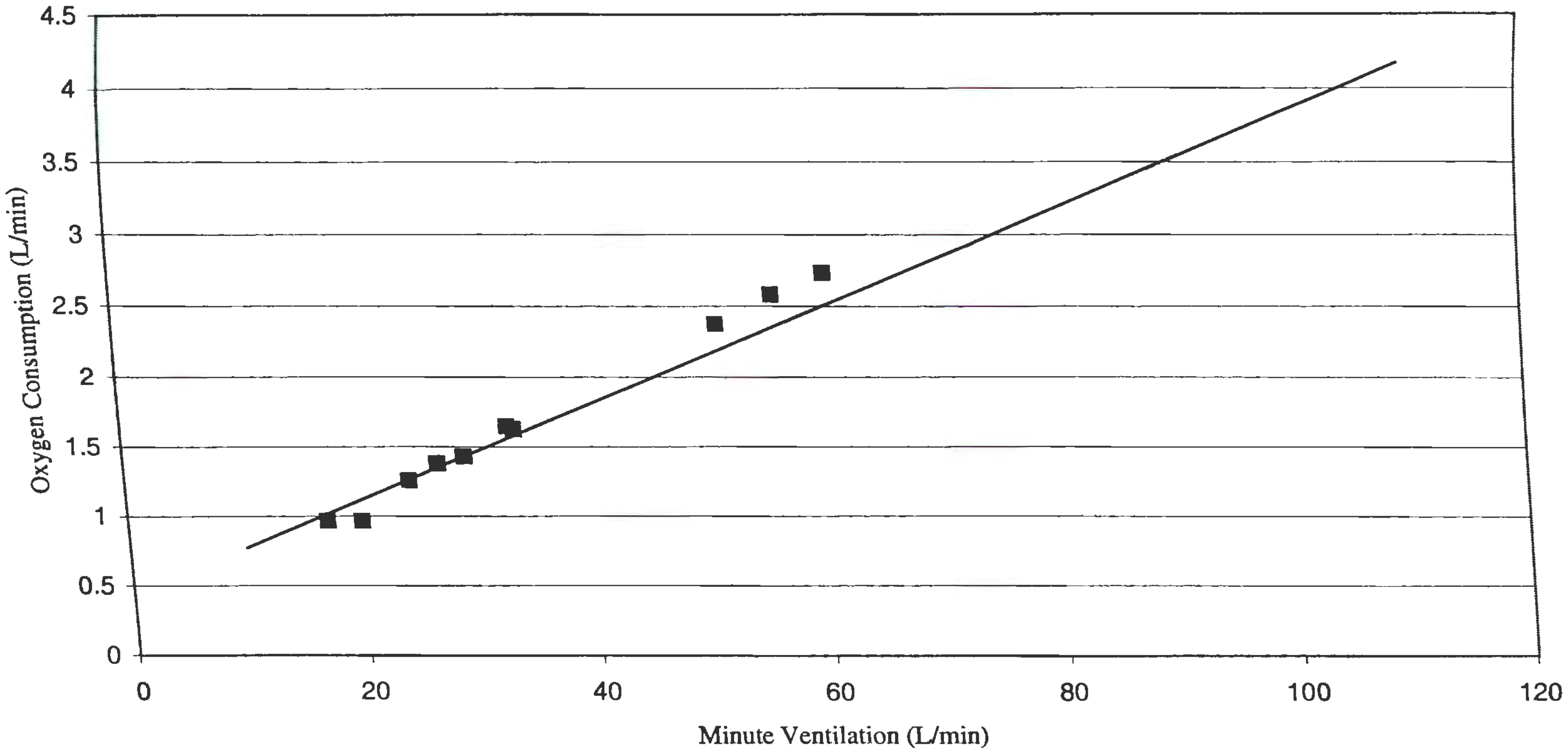

Figure 37. Validation data plotted against the best fit line from regression of oxygen consumption against minute ventilation.

The data and the regression line are plotted in Figure 38.

$$V_{O2} = 1.3851V_T + 0.2896 \tag{92}$$

where: V_T, tidal volume, L

V_{O2}, oxygen consumption, L/min

The correlation coefficient, standard error ratio of the model, and standard error ratios of the slope and intercept coefficients were 0.924, 0.388, 0.068, and 0.414, respectively. The high correlation coefficient indicated that there was a strong relationship between the two variables. The standard error ratio of the model indicates whether any improvement in prediction accuracy has occurred with the model. The ratio of 0.388 indicated that a large increase in prediction accuracy occurred. The standard error ratios of the coefficients indicated the accuracy of the coefficients. McCuen (1993) found from experience that values greater than 0.3 to 0.4 may indicate a coefficient of questionable accuracy. So, the slope coefficient was accurate, but the intercept coefficient may be of questionable accuracy. The model bias was zero, indicating that the model neither consistently over- nor under-predicted.

There was not a pattern to the residuals (see Appendix B, 124). The percent errors ranged from –31% to 53% with 90% of the errors within ± 30%. Eighty-seven percent of the errors were within 25%.

Figure 39 shows the validation data plotted with the regression line. The percent errors ranged from –30% to 42%. Ninety percent of the errors were within ±

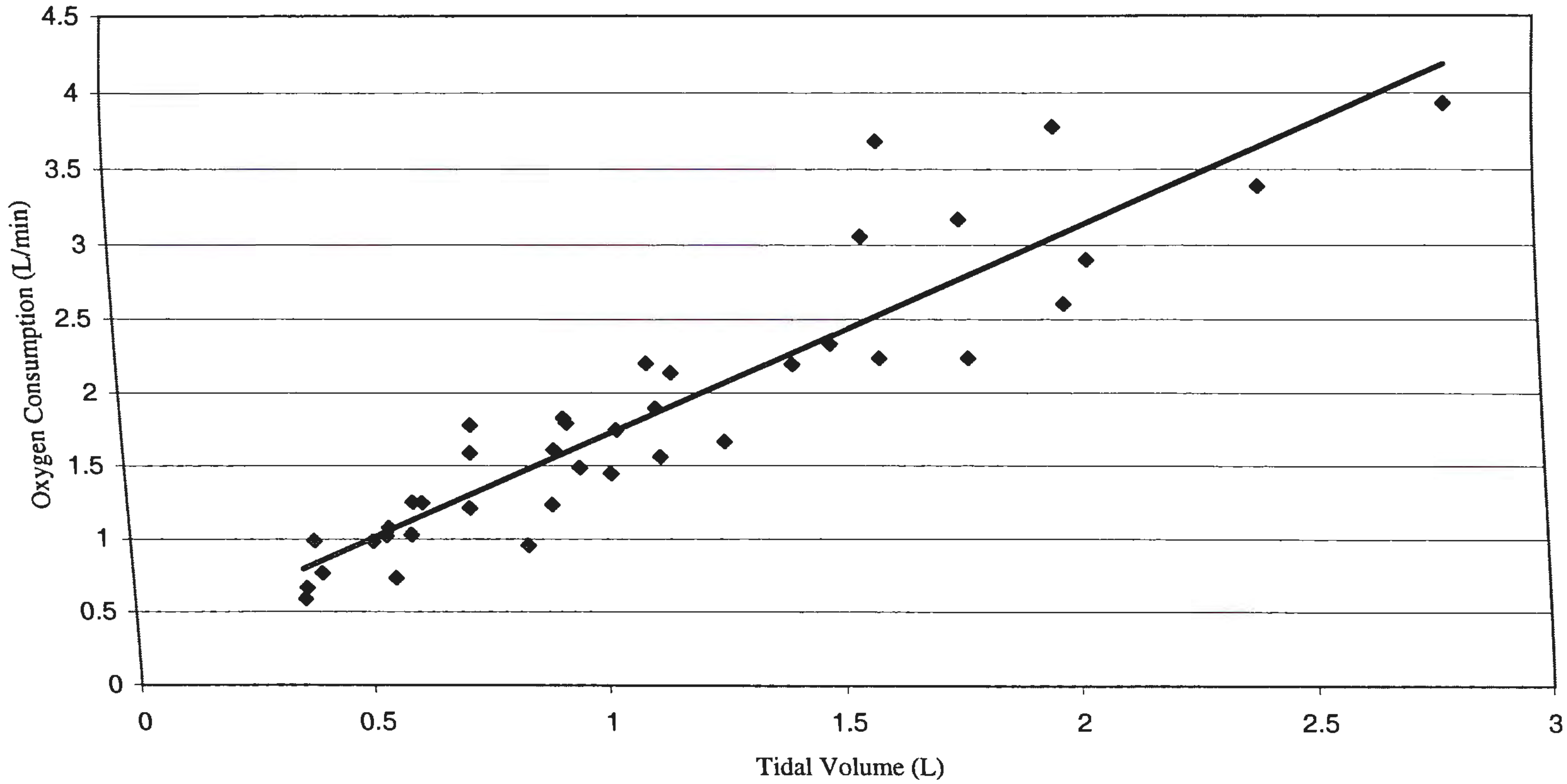

Figure 38. Oxygen consumption and tidal volume data from the levels determination session. Shown is the best fit line.

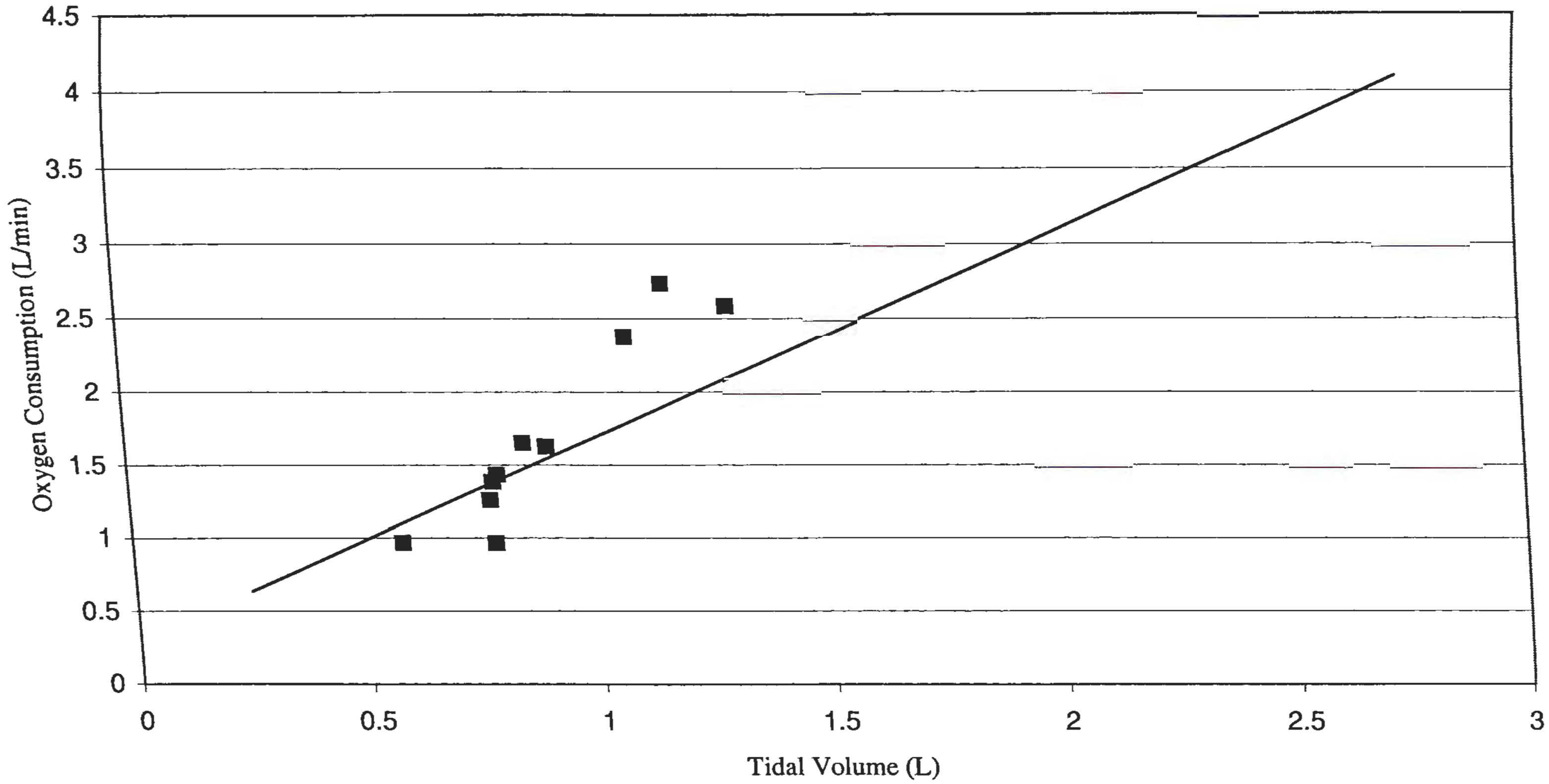

Figure 39. Validation data plotted against the best fit line from regression of oxygen consumption against tidal volume.

30% and eighty percent were within 25%. The errors with the validation data were similar to the errors seen with the calibration data.

The predictions made with equation 87 were unbiased and a high degree of correlation was found between oxygen consumption and tidal volume. The intercept coefficient was of questionable accuracy; this may have led to the larger errors. However, overall, the model fit the data well.

Actual Oxygen Consumption

Actual oxygen consumption was determined using the equation for oxygen consumption as a function of minute ventilation. This equation was selected over the tidal volume equation due to the larger errors in the tidal volume equation and the intercept coefficient with questionable accuracy. Both equations were determined in order to see which equation was more accurate.

Oxygen Deficit

Oxygen deficit was found as the difference between the oxygen consumption required by the activity and the oxygen consumption adjusted for the resistance and dead volume of the respirator:

$$O_2\ \text{deficit} = V_{O2,\text{required}} - V_{O2,\text{adjusted}} \qquad (93)$$

where: O_2 deficit, oxygen deficit, L/min

Because transient effects were not included in the model, no direct predictions of performance time for respirator wearers may be made. However, the difference between the oxygen consumption required by the activity and the modified oxygen consumption of the respirator wearer would give an indication of the oxygen deficit. Activities with a large oxygen deficit would not be able to be continued for a long time.

Performance Time

While accurate predictions of performance time can not be made presently, a rough estimate of performance time was added to the model. The predictions of performance time should in no way be considered reliable. This parameter was added for two reasons. The first was to provide very rough estimates of performance time so that different respirators could be compared. The second and main reason was that eventually the model will be able to make predictions of performance time so performance time was added to provide the structure for future development of the model.

Bearden and Moffatt (2000) found that the maximum oxygen deficit for work above the anaerobic threshold was 4.03 L. This value was used as the maximum oxygen deficit in the present model. If the maximum deficit were divided by the actual deficit, a performance time could be predicted. Therefore, the equation for performance time was:

$$\text{Perf time} = \left(\frac{4.03}{O_2 \text{ deficit}} \right) \tag{94}$$

where: Perf time, performance time, min

Respiratory Rate and Respiratory Period

Respiratory rate was found by dividing the adjusted minute ventilation by the adjusted tidal volume:

$$RR = \frac{V_{E,\text{adjusted}}}{V_{T,\text{adjusted}}} \tag{95}$$

where: RR, respiratory rate, breaths/sec

Respiratory period was determined from the inverse of the respiratory rate:

$$RPD = \frac{1}{RR} \tag{96}$$

where: RPD, respiratory period, sec

Exhalation and Inhalation Times

The theoretical model developed by Johnson and Masaitis (1976) was not used to determine the inhalation and exhalation times because preliminary analysis of the data from the inhalation/exhalation study (Johnson, et al., 2001b) indicated that the model was not producing reliable results. Caretti et al. (1992) had indicated that a power-law relationship existed between exhalation time and respiratory rate. It was believed that if the same relationship could be shown for a large data set, then this relationship could be used to directly calculate exhalation time from respiratory rate.

The data from the inhalation/exhalation study showed a power-law relationship similar to that obtained by Caretti et al. (1992) (see Appendix B, Figure 125). The variability of the data in the region below 20 breaths/min was larger than the variability above 20 breaths/min. This variability was seen also by Caretti et al. (1992).

Figure 40 shows the exhalation time plotted against the respiratory period, the regression line, and the regression equation. There was a larger variability in the data at the longer respiratory periods. The regression equation was:

$$T_{exh} = 0.6176RPD - 0.2145 \qquad (97)$$

where: T_{exh}, exhalation time, sec

RPD, respiratory period, sec

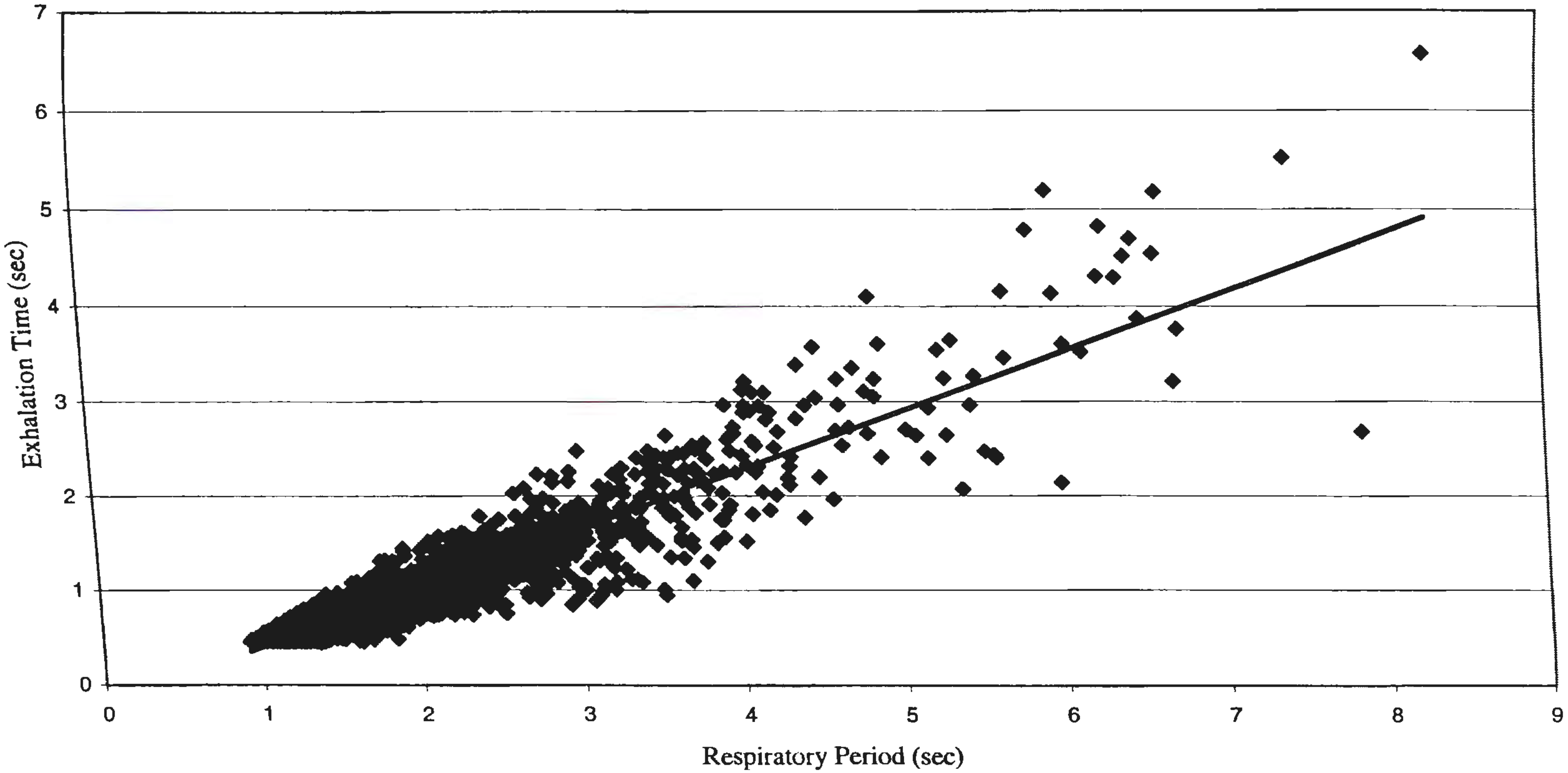

Figure 40. Exhalation time and respiratory period calibration data. Shown is the best-fit line.

The analysis of the regression line resulted in the following statistics: R= 0.93, $S_e/S_y = 0.36$, $S_e(b_1)/b_1 = 0.01$, $S_e(b_0)/b_0 = -0.03$, and bias = 0.00. These statistics indicated that the model was accurate. The fact that the ratio S_e/S_y is much less than one indicates that the predictions made with the model are a significant improvement over predictions that would be made using the mean. The standard error ratios for the slope and intercept coefficient are close to zero, which indicated that they are reasonably accurate. Finally, the model provided unbiased estimates and had a high correlation coefficient.

The residuals showed that as respiratory period increased, the spread of the predicted values increased (see Appendix B, Figure 126). However, the same pattern was seen with the raw data: there was more variability as respiratory period lengthens. This variability was seen by other researchers (Caretti et al., 1992). It seemed logical that if the raw data had a higher variability in one region then the predicted values would exhibit a higher variability as well.

Analysis of the percent errors in the residuals indicated that there were 722 predicted values that were greater than ± 20%, 110 greater than ±40%, and 1 greater than ±100%. This meant that 84% of the predicted values were within ±20% of the actual value and 97.5% were within ±40% of the actual value.

The validation data and regression line are shown in Figure 41. The resulting regression equation was:

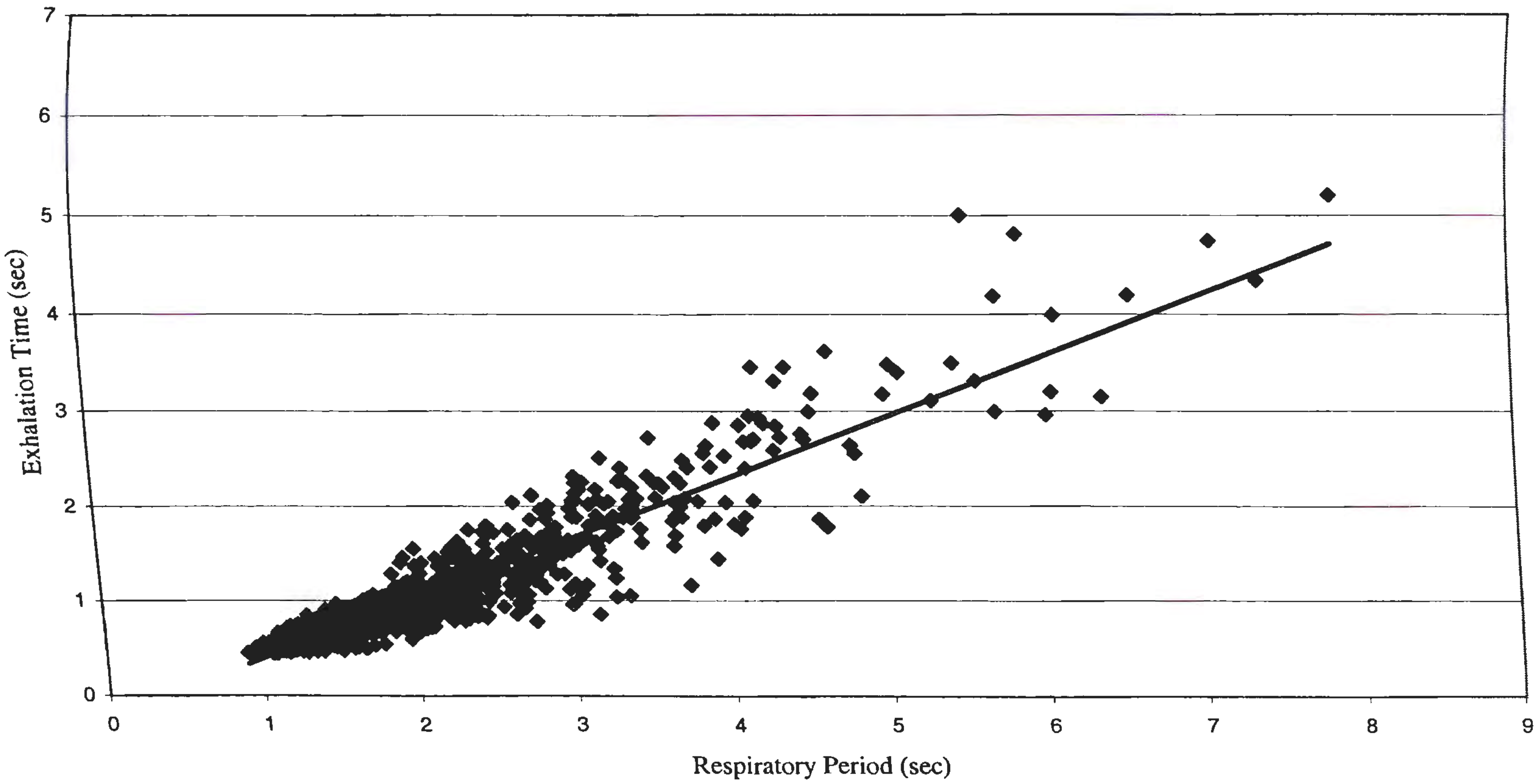

Figure 41. Exhalation time and respiratory period validation data plotted with the linear regression line obtained from the calibration data.

$$T_{exh} = 0.627RPD - 0.2325 \tag{98}$$

The calculated t-values were 0.73 and –1.59 for the slope and intercept coefficients, respectively. Both t-values were within the accepted range. Thus, the null hypothesis was accepted. The slope and intercept coefficient obtained for the validation data were the same as the slope and intercept coefficients for the calibration data.

Caretti et al. (1992) showed that a power-law relationship existed between exhalation time and respiratory rate. The current analysis indicated that a similar relationship existed. The change of variable from respiratory rate to respiratory period simplified the statistical analysis. The statistics indicated that the model (equation 98) provided an accurate, unbiased prediction of the exhalation time over the range of respiratory periods from 0.9 to 8 seconds.

During exercise, inhalation time can be obtained by subtracting the exhalation time from the respiratory period. At rest, there is a brief pause between exhalation and inhalation.

Breathing Waveform Based on Work Rate

The inhalation waveform changes from sinusoidal at rest to trapezoidal during moderate intensity exercise. The exhalation waveform begins as an exponential at rest and becomes trapezoidal during exercise. When flow rate becomes limited during heavy exercise, exhalation becomes exponential (Johnson, 1991). While

Johnson and Berlin (1974) investigated the transition from a trapezoidal exhalation waveform to a limited-flow exponential, the work rate at which the waveforms transition from sinusoidal inhalation and exponential exhalation to trapezoidal is unknown. The waveform transition was assumed to occur at 40% V_{O2max}.

At heavy work rates, there is a partial collapse of the airways due to high external pressures and high internal flow rates (Johnson, 1993). Because of this, flow becomes limited. Johnson and Berlin (1974) found that limited expiratory flow was a factor in termination of exercise for young men wearing respiratory protective masks. The exhalation time at exhaustion was 0.66 seconds. Therefore, when exhalation time was 0.66 seconds or below, the exhalation waveform was assumed to be a flow-limited exponential.

Respiratory Work Rate

Respiratory work rate equations for sinusoidal, trapezoidal, hybrid exponential, and flow-limited hybrid exponential waveforms were obtained from Johnson (1993). Values for the Rohrer coefficients, compliance and inertance were taken from the same study.

Implementing and Evaluating the Model

The model was implemented in a Visual BASIC program. Default values were provided for all inputs so that a user could start the program and run it without entering any values. Four respirator conditions were possible. The default condition was no respirator worn. The U. S. Army M17 and M40 masks were possible options. These were added because these masks have been used in many studies. Data from the literature could be simulated by selecting one of these two masks. The fourth option was to allow the user to enter values for inhalation and exhalation resistance, dead volume, and mass.

Four possibilities were available for the external work rate as well. The user could choose to enter a work rate, select a treadmill speed and grade, select bike ergometer values, or select stepping values.

All outputs were displayed in text boxes on the screen. Buttons were provided to allow the user to get to the forms where the data was entered. The name of the output file could be chosen by the user.

The program was intended to be user friendly and easy to use. The program was structured so that future development of the model could be incorporated easily.

The evaluation of the model occurred in three stages. The model equations were first checked to ensure that they had been entered correctly. Data from six subjects was then used to evaluate the model predictions. Finally, simulations were run for a respirator and no respirator condition.

Model Equations

The input values given in Johnson (1993) were entered into the current model and the results compared to the results presented in the paper. The work rates for the sinusoidal, trapezoidal, hybrid exponential, and limited-flow hybrid exponential obtained with the current model matched those presented in Johnson (1993).

Other equations in the model were checked by calculator and by spreadsheet to ensure that mistakes had not been made either in entering the equations or in the logic that dictated their use. In all cases, the model and validation calculations were equal.

Subject Simulations

Demographic data for subjects 002, 224, and 230 are shown in Table 17.

Table 17. Demographic information for three validation subjects.

Subject	Age (yr)	Height (cm)	Weight (kg)	V_{O2max} (L/min)
002	34	160	58	2.38
224	22	163	60	3.45
230	18	175	63.5	3.23

The test conditions for each stage are presented in Table 18.

Table 18. Treadmill speeds and grades for the five stages. Speeds are in m/s and grades are in percent. The information is presented as speed/grade.

	002	224	230
Stage 1		0.76 / 0	1.12 / 0
Stage 2		1.21 / 0	1.57 / 0
Stage 3		1.7 / 0	1.7 / 3
Stage 4	1.7 / 0*	1.97 / 6	2.15 / 4
Stage 5		1.97 / 10	

* Subject was at 60% V_{O2max}, below the targeted 65-70%.

The plots of the actual and model simulation results for oxygen consumption, minute ventilation and tidal volume are shown in Figures 42 - 44. Clearly, the model did not make very good predictions. Percent errors for oxygen consumption, minute ventilation, and tidal volume, respectively ranged from –57 to 15, -66 to 58, and –58 to 9.

As minute ventilation and tidal volume are functions of oxygen consumption, errors in determining the oxygen consumption will be compounded when minute ventilation and tidal volume are determined. Possible errors in determining the oxygen consumption were errors in the relationship between oxygen consumption and physiological work rate and errors in determining the physiological work rate.

Physiological work rate in this model was determined from the external work rate and efficiency. It was known that there were problems with determining external work on a treadmill. Additionally, the efficiency equation was evaluated using a small number of data points. As mentioned previously, errors in one relationship get compounded when other parameters are based on the faulty relationship. As the Pandolf et al. (1977) equation has been shown to make accurate predictions of physiological work rate for subjects exercising on a treadmill (Myles and Saunders, 1979), it was decided to use the Pandolf equation for all subjects exercising on a treadmill. This bypasses the external work rate and efficiency calculations. Additional work should be performed to investigate improvements in determining external work rate and efficiency.

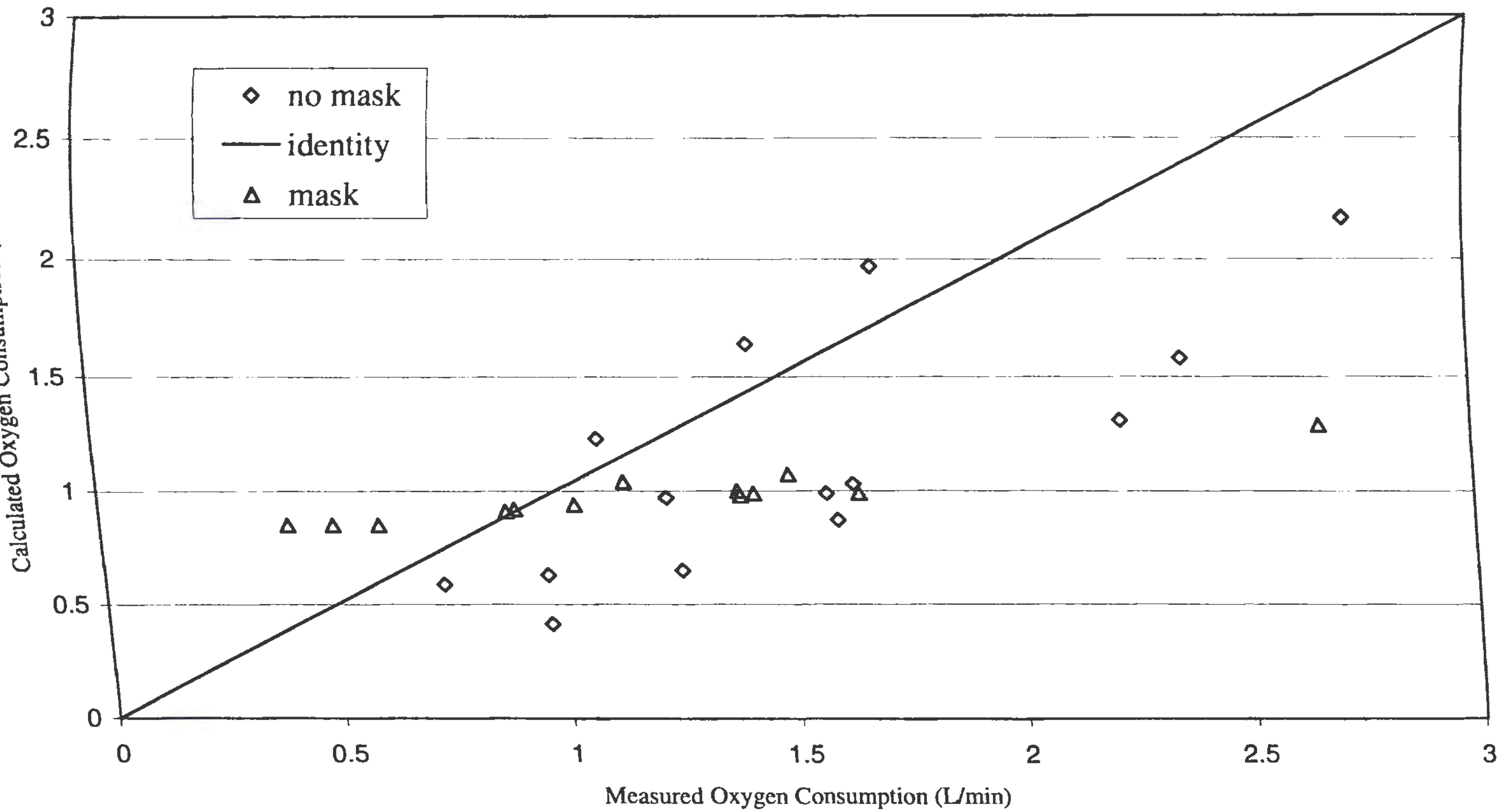

Figure 42. Oxygen consumption calculated by the model compared to measured oxygen consumption.

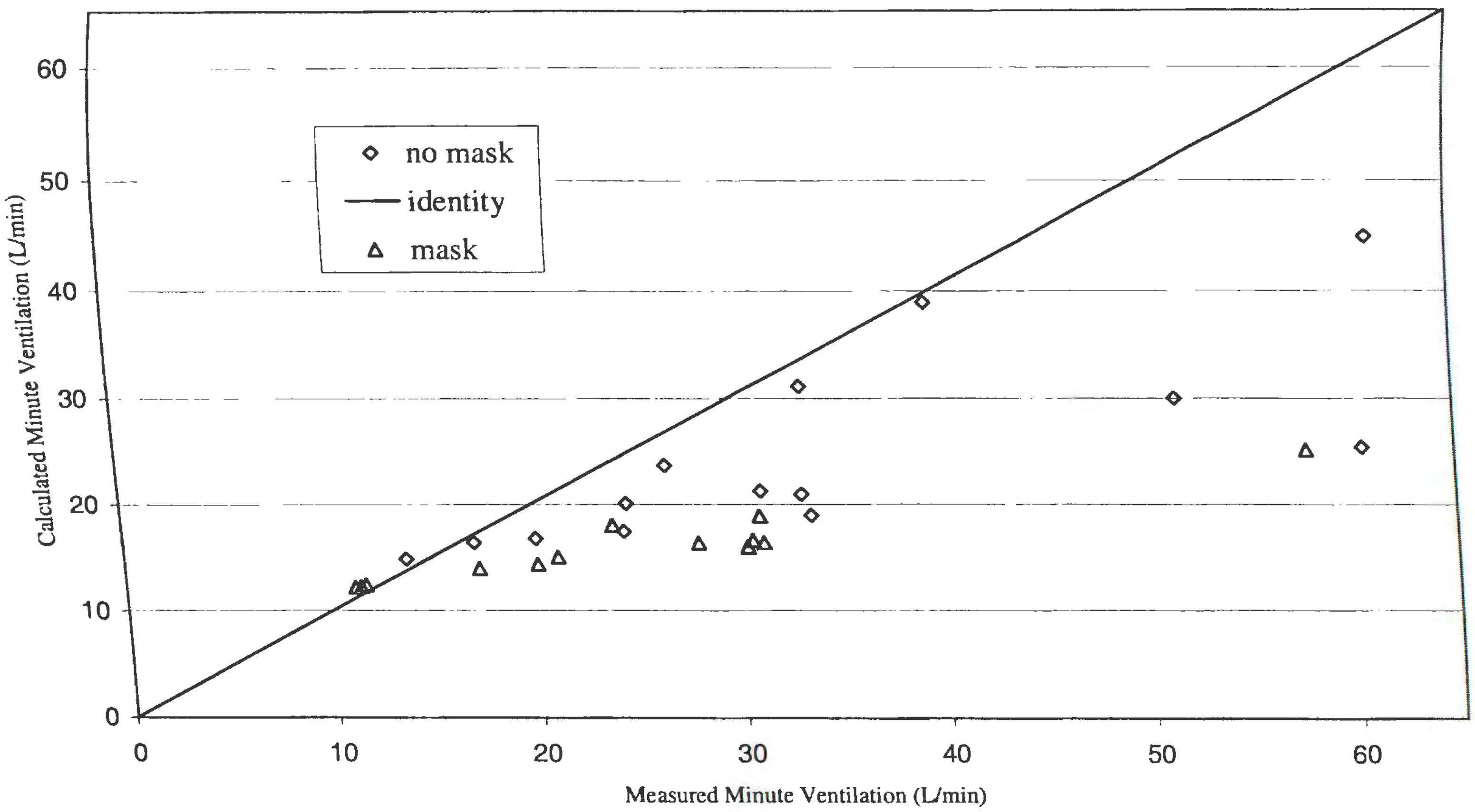

Figure 43. Minute ventilation calculated by the model compared to measured minute ventilation.

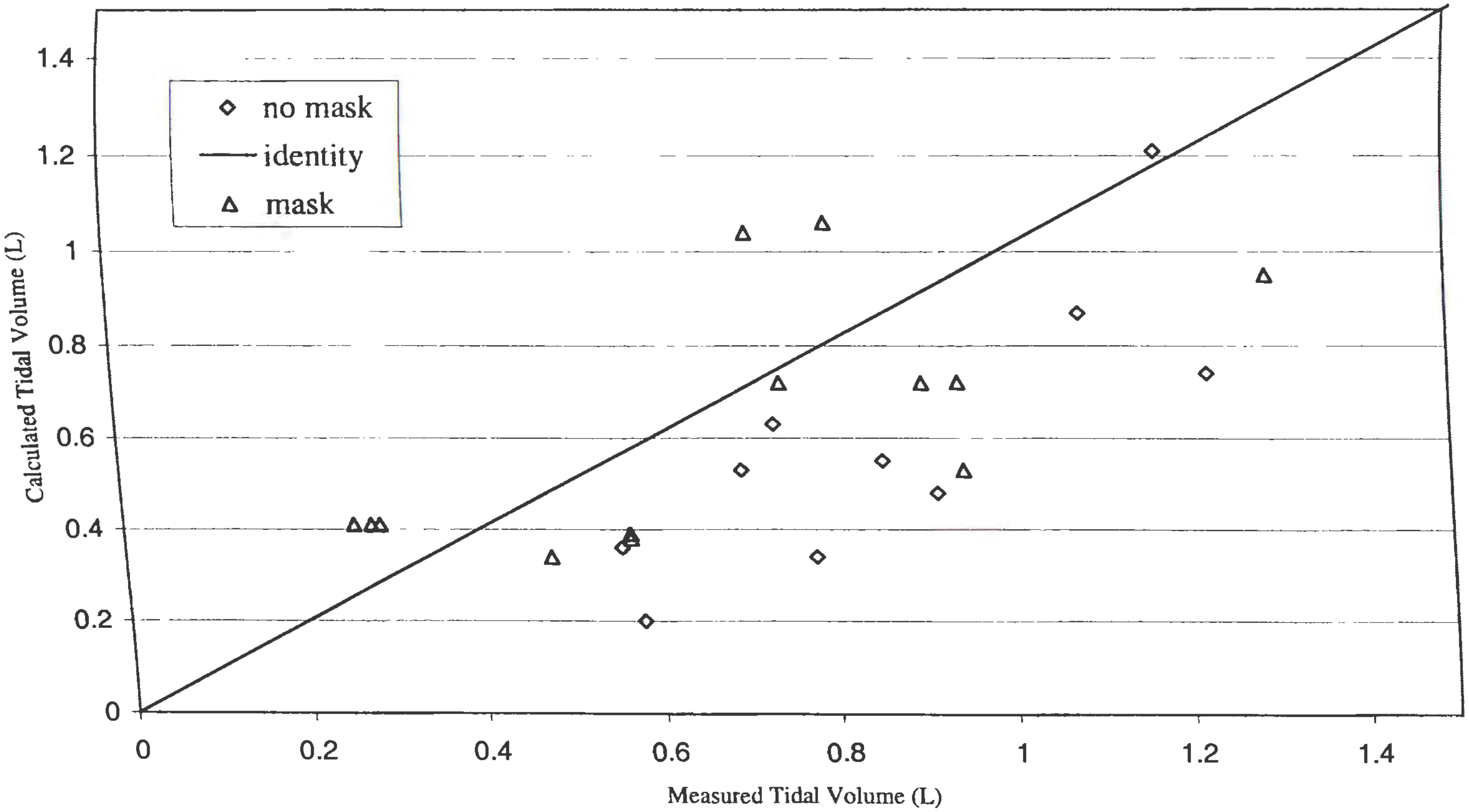

Figure 44. Tidal volume calculated by the model compared to measured tidal volume.

The reason for trying to use external work rate and efficiency instead of equations such as Pandolf was that the external work rate/efficiency method should be applicable across different physical activities. Equations such as Pandolf and those developed by ACSM (2000) are applicable only to certain activities. As respirator wearers are not always walking on a treadmill, stepping, or cycling, a method of determining the physiological work rate is needed for various activities.

The relationship between oxygen consumption and physiological work rate was evaluated also. The graph presented by Astrand and Rodahl (1970) and the equation developed here (equation 55) showed a zero-intercept linear equation. The data from the current study are shown in Figure 45. The linear regression equation fit to the data was:

$$V_{O2} = 0.0028WR_{phys} + 0.4398 \qquad (99)$$

where: WR_{phys}, physiological work rate, W

V_{O2}, oxygen consumption, L/min

The slope is very close to the slope of equation 55 (0.0029). However, equation 99 shows that there is a large intercept. Both the slope and the intercept were found to be significantly different from zero. The correlation coefficient was 0.98, the bias was zero, and the standard error ratio was 0.21. All of these statistics indicated that equation 99 was statistically valid. The standard error ratios of the slope and intercept coefficient were 0.04 and 0.14. Values less than 0.3 to 0.4 indicate accurate predictors (McCuen, 1993).

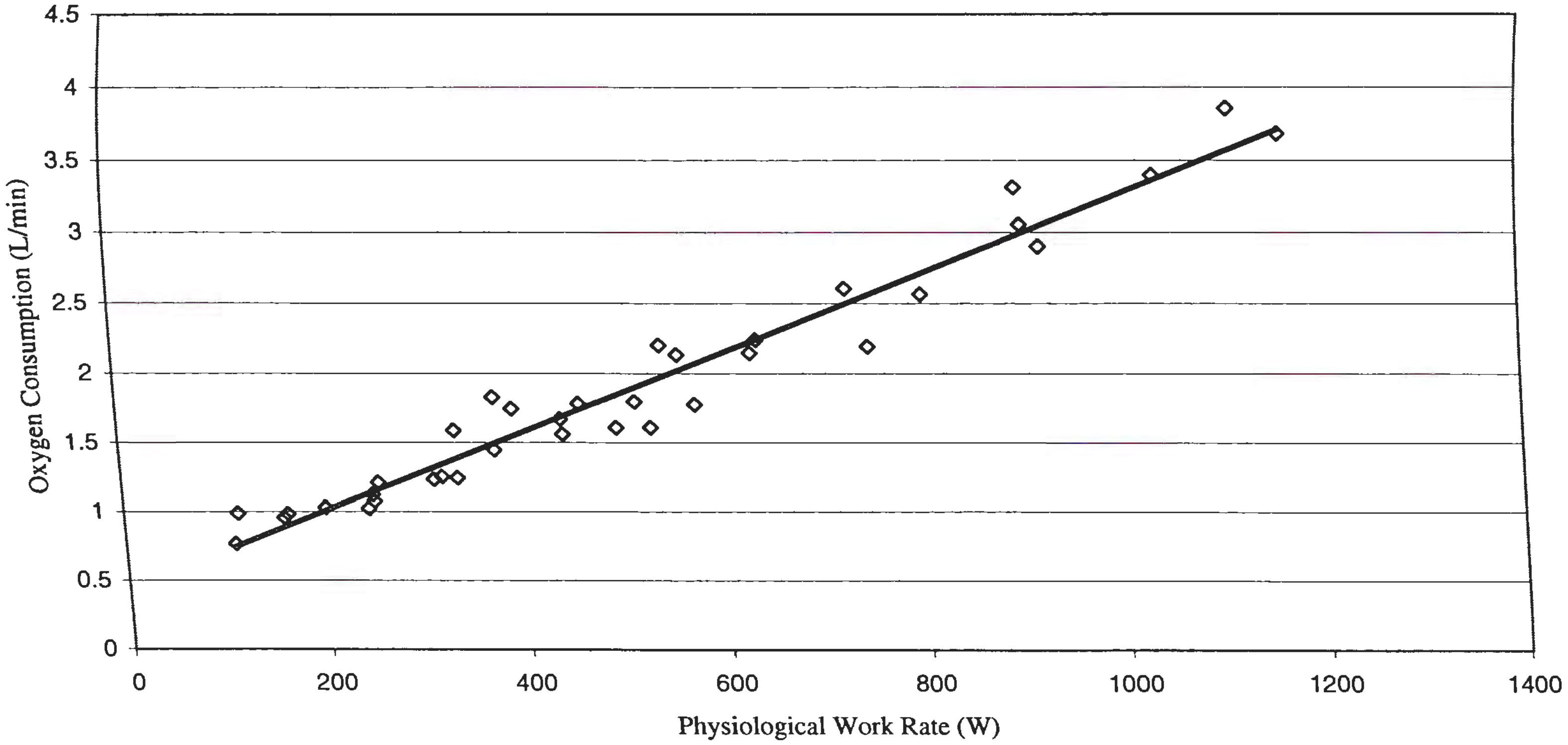

Figure 45. Required oxygen consumption and physiological work rate. Data are from the levels determination session from the current study.

Equation 99 replaced the previous relationship between oxygen consumption and physiological work rate in the model. The physiological work rate was determined from the Pandolf et al. (1977) equation. Model simulations were run again for subjects 002, 224, and 230. Plots of the calculated versus measured oxygen consumption, minute ventilation, and tidal volume are shown in Figures 46 - 48. The percent errors for oxygen consumption, minute ventilation, and tidal volume, respectively ranged from –28 to 18, -27 to 88, and –32 to 15. Three of the errors for tidal volume were greater than fifty percent. The rest of the errors were below 21%. The modified model made much better predictions of oxygen consumption, minute ventilation, and tidal volume than the original model. The errors in the calculations here are of a similar magnitude to those of the original equations.

The plots of the data from the three subjects who participated in the inhalation / exhalation resistance study for oxygen consumption, minute ventilation, and tidal volume are shown in Figures 49 - 51. The oxygen consumption and minute ventilation are consistently under-predicted. Errors in the prediction of oxygen consumption, minute ventilation, and tidal volume, respectively ranged from –52 to 41, –48 to 0, and -31 to 73. The model was not making accurate predictions at high work rates.

There were large decreases in the minute ventilation due to the resistance of the respirator. If there were an error in determining the adjusted minute ventilation, then there would also be an error in determining the adjusted oxygen consumption based on that minute ventilation. A multiple regression equation was fit to the minute ventilation and inhalation and exhalation resistance data to determine if there were a

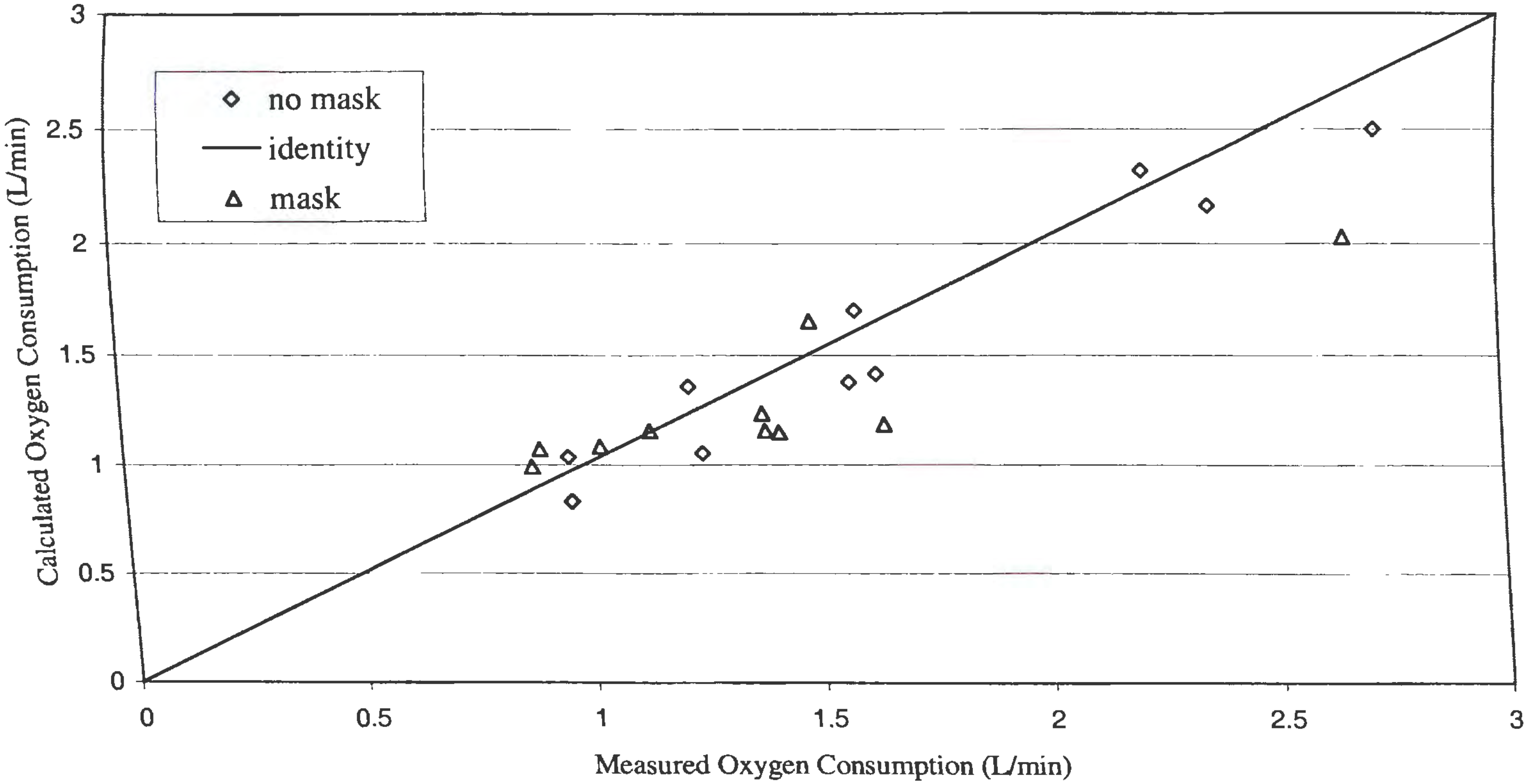

Figure 46. Oxygen consumption calculated by the model compared to measured oxygen consumption after changes to the model.

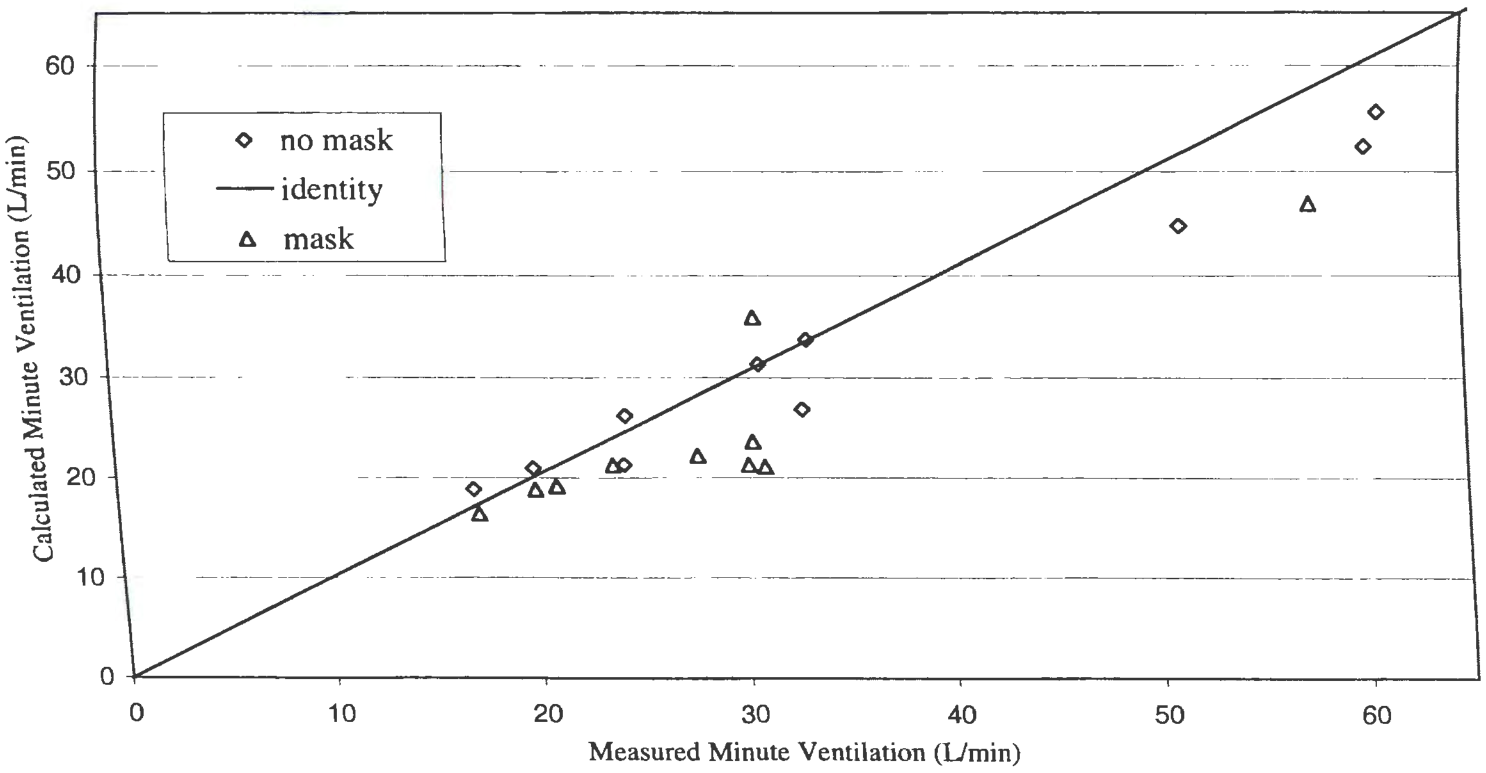

Figure 47. Minute ventilation calculated by the model compared to measured minute ventilation after changes to the model.

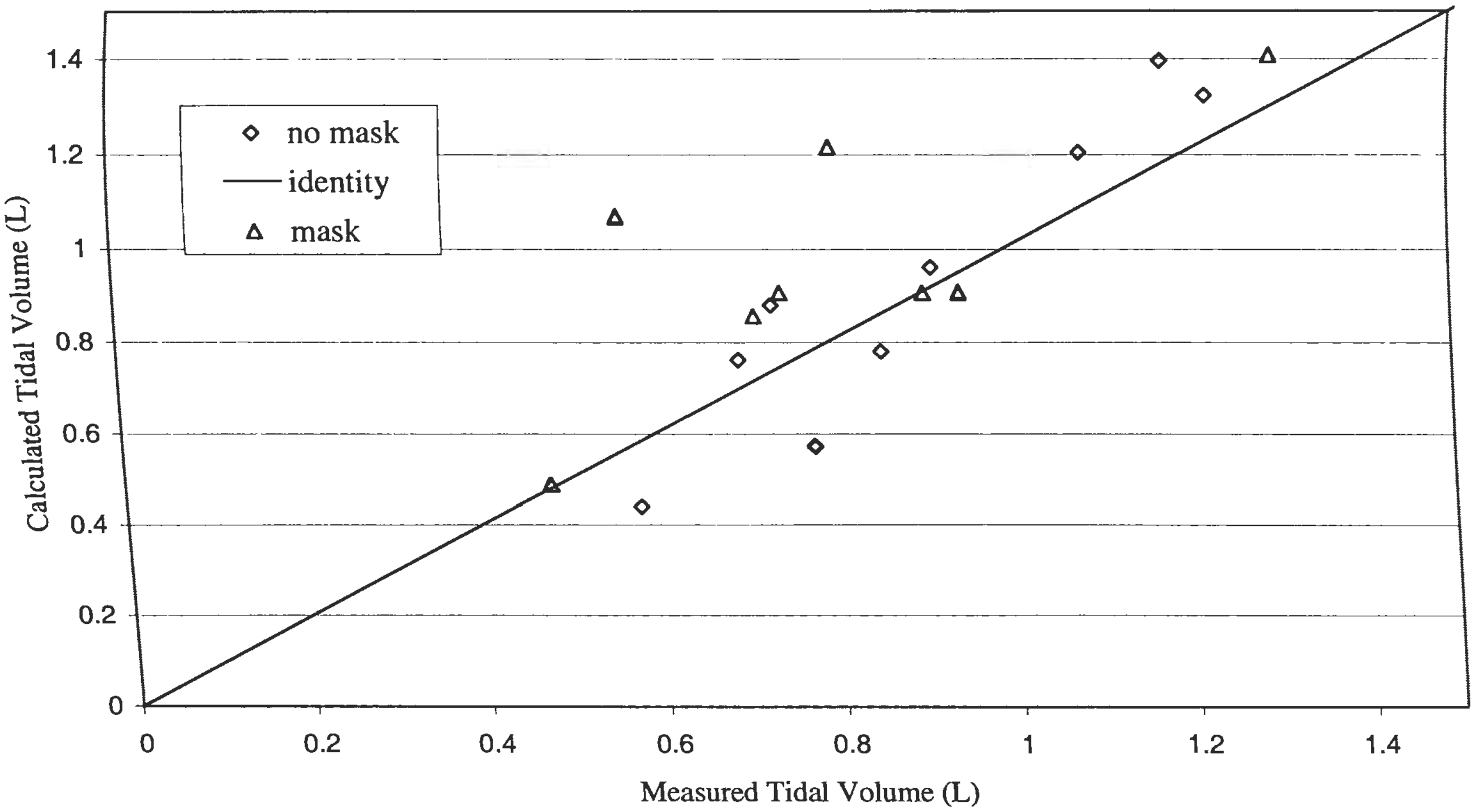

Figure 48. Tidal volume calculated by the model compared to measured tidal volume after changes to the model.

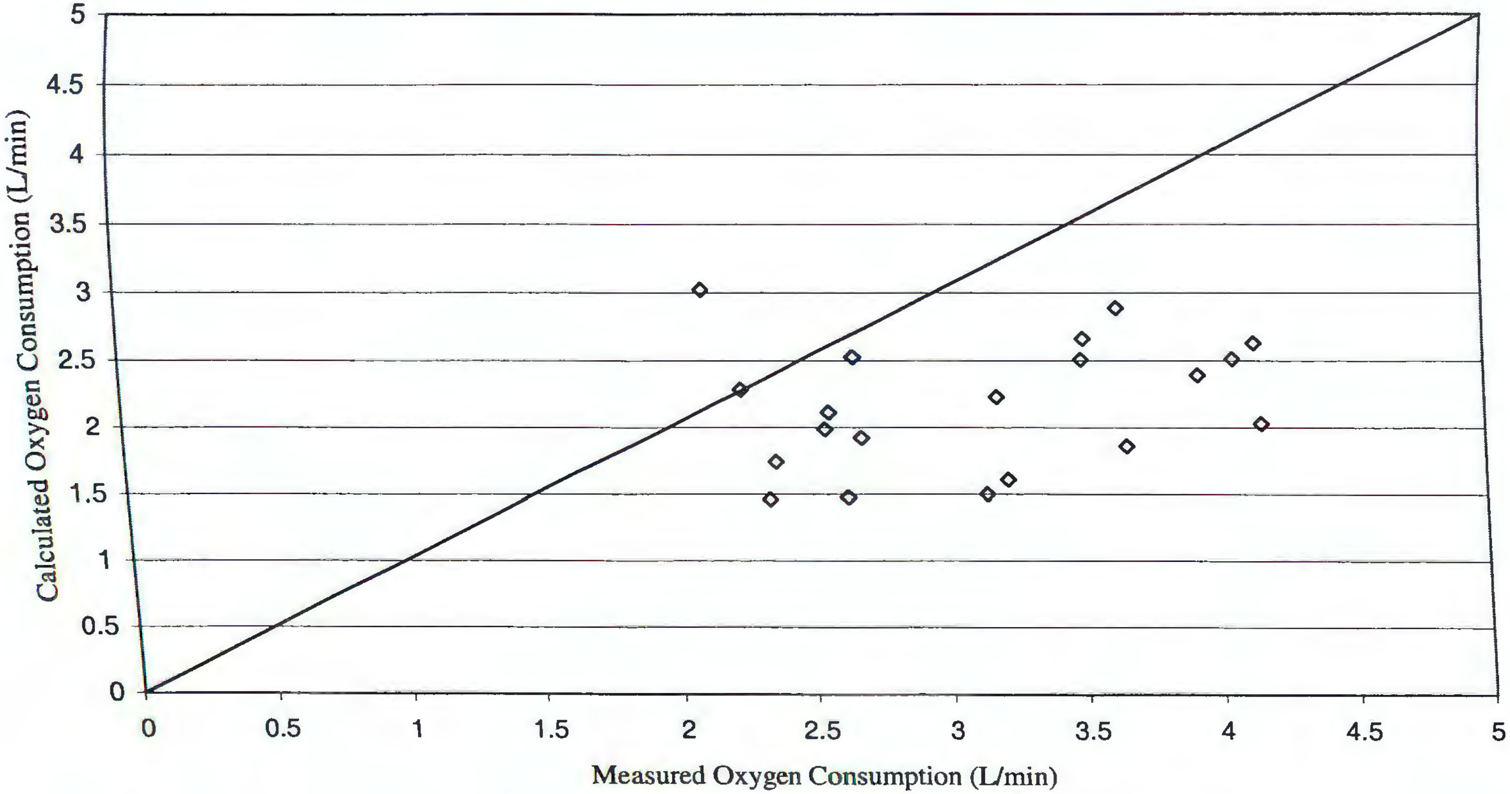

Figure 49. Oxygen consumption calculated by the model compared to measured oxygen consumption for subjects who completed a study on inhalation and exhalation resistance.

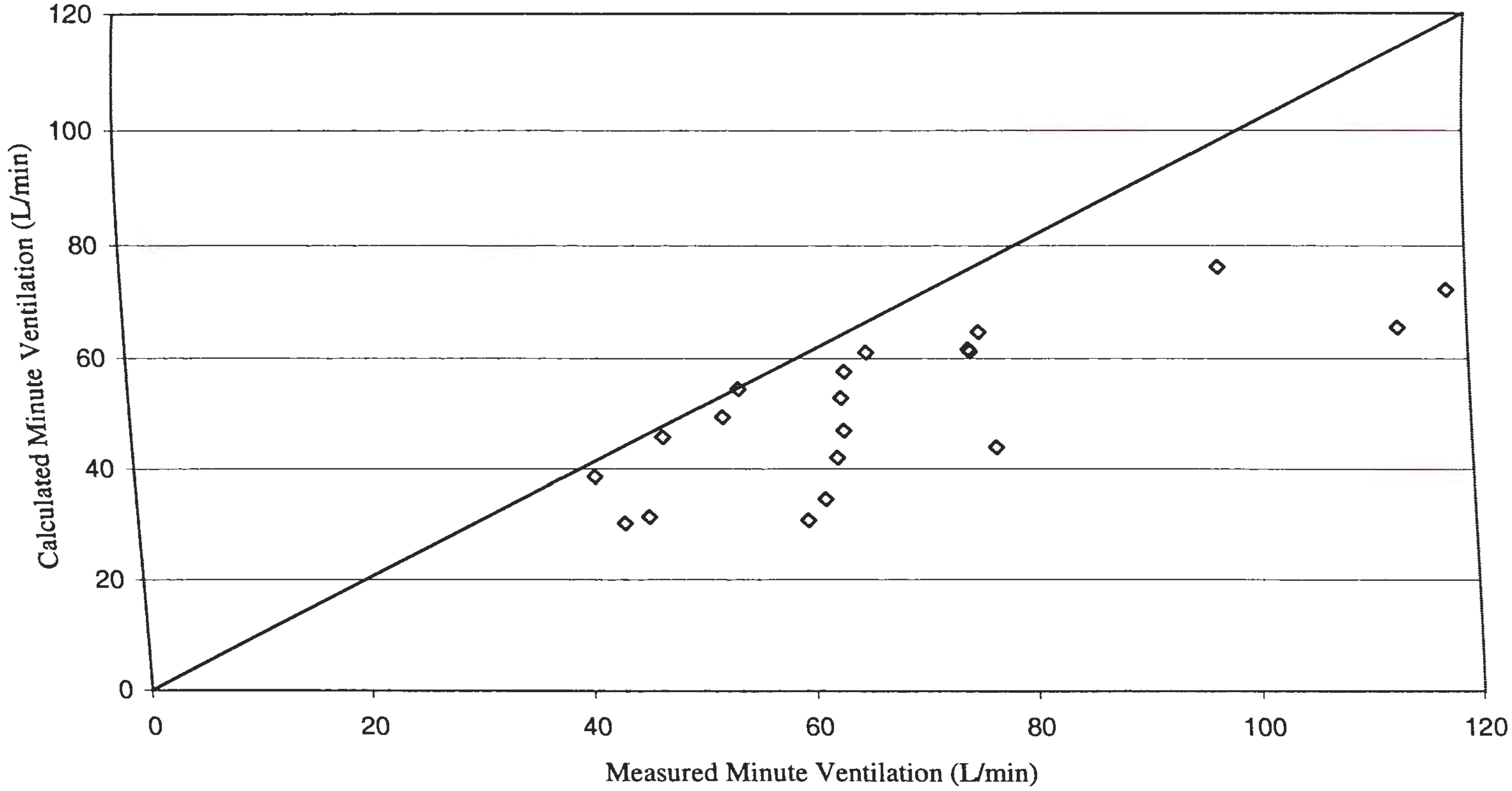

Figure 50. Minute ventilation calculated by the model compared to measured minute ventilation for subjects who completed a study on inhalation and exhalation resistance.

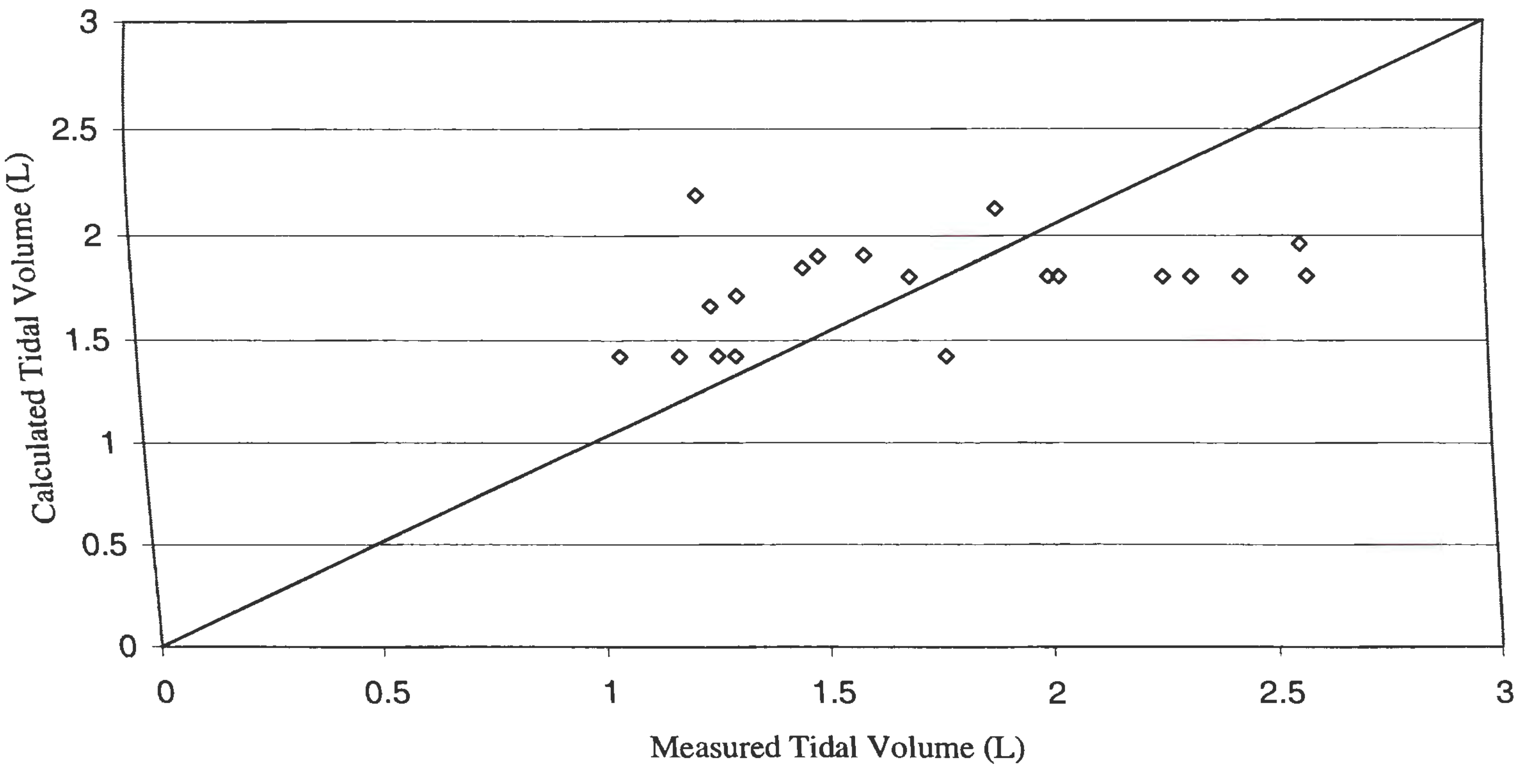

Figure 51. Tidal volume calculated by the model compared to measured tidal volume for subjects who completed a study on inhalation and exhalation resistance.

drastic difference between the effect of resistance with these subjects and the effects shown in the study conducted as part of this research. The resulting equation was:

$$V_E = 1.48 - 0.024R_{inh} - 0.0758R_{exh} \qquad (100)$$

where: R_{inh}, inhalation resistance, $cmH_2O/L/s$

R_{exh}, exhalation resistance, $cmH_2O/L/s$

V_E, minute ventilation, L/s

The slopes of the above equation are similar to those for the equation developed previously. The slopes of equation 79 were –0.045 for inhalation resistance and –0.0967 for exhalation resistance. So, it does not appear that the previously developed equation x was unreasonable.

Two possible reasons for the discrepancy between the predicted and actual values could be the small sample size and the fact that equation 79 was based on average minute ventilation values. Because of the variability in physiological data, using small sample sizes can lead to errors in equations fit to the small sample. However, as was discussed previously, the slopes of the inhalation and exhalation resistance are consistent with values found in the literature. The present slopes do differ from those found by Johnson et al. (1999) and Caretti et al. (2001). Caretti et al. reported that the effects of inhalation resistance were three times greater than those of exhalation resistance. Perhaps the results of the study on the combined effects of inhalation and exhalation resistance (Johnson et al., 2001b) will help resolve this difference.

Model simulations were run using data from the stage 5 respirator condition B from the current study. The percentage errors for oxygen consumption, minute ventilation, and tidal volume ranged from –36 to 14%, -34 to 2%, and –38 to 34%, respectively. These errors are closer to the errors of the original equations. This would be expected since the equations were based on the data of these eight subjects. But, it does show that the model was performing as expected based on the small population on which the equations were based.

The second possible reason for the discrepancy in predicted versus actual values is that average minute ventilations at each stage were used to make the predictions of the effects of inhalation and exhalation resistance. Additionally, the regression equations for the effects of resistance assume that the amount of the decrease in minute ventilation is dependent on the resistance and work rate only and not on the minute ventilation with zero external resistance. The percent change in minute ventilation may be a better approach than an absolute change.

To investigate the possibility of using percent changes in minute ventilation, the difference in minute ventilation from the levels determination session to each of the respirator conditions was determined for stage four for the eight subjects who participated in the current study. The results are shown in Table 19.

Table 19. Percent changes in minute ventilation for subjects exercising at 65-70% of V_{O2max}. Respirator conditions are compared to the levels session.

Subject	Respirator A	Respirator B	Respirator C
001	-4.3	-11.6	0.66
002	-1.3	-2.6	-0.7
023	-2.5	-3.2	0.3
145	-6.6	-1.2	-7.3
173		-4.4	-10.3
214	-15.9	-24.8	-25.4
221	6.5	-3.2	-3.9
231	-0.6	1.2	2.4

The percent changes show the variability in the response of the subjects to external resistance. Subject 214 evidenced large decreases in minute ventilation while subject 231 appeared to be relatively insensitive to changes in resistance. Subjects 001, 023, 221, and 231 each had at least one instance where minute volume increased with the resistance. These increases were relatively small although subject 221 had a 6.5% increase in minute ventilation going from the levels session to respirator A. It does not appear that using percent changes in minute ventilation would result in better predictions.

Some subjects are more sensitive to resistance than others. Perhaps individual multiple regression equations should be developed that relate minute ventilation not only to inhalation and exhalation resistance but also to other factors such as anxiety and respiratory resistance as well. Further investigation would be necessary to determine if such equations would improve the prediction accuracy of the model. Johnson et al. (1999) also had some subjects who were insensitive to resistance. Those authors were unable to determine a distinguishing factor among those subjects.

A study should be conducted in which a large number of subjects perform exercise at a variety of work rates while wearing respirators with different combinations of resistance and dead volume. This data would be used to examine the model equations and the validity of the overall model. Sufficient data to conduct a full validation and sensitivity analysis of the model was not available.

Mask/No Mask Simulations

Plots of adjusted minute ventilation, adjusted tidal volume, adjusted oxygen consumption, respiration rate, inhalation time, exhalation time, inspiratory work rate, expiratory work rate, inspiratory work, expiratory work, total respiratory work, and total respiratory work rate versus percent of maximum oxygen consumption obtained from model simulations of mask and no mask conditions are shown in Figures 52 to 63. The $\%V_{O2max}$ was obtained from the required oxygen consumption for both the mask and no mask conditions so that direct comparisons could be made.

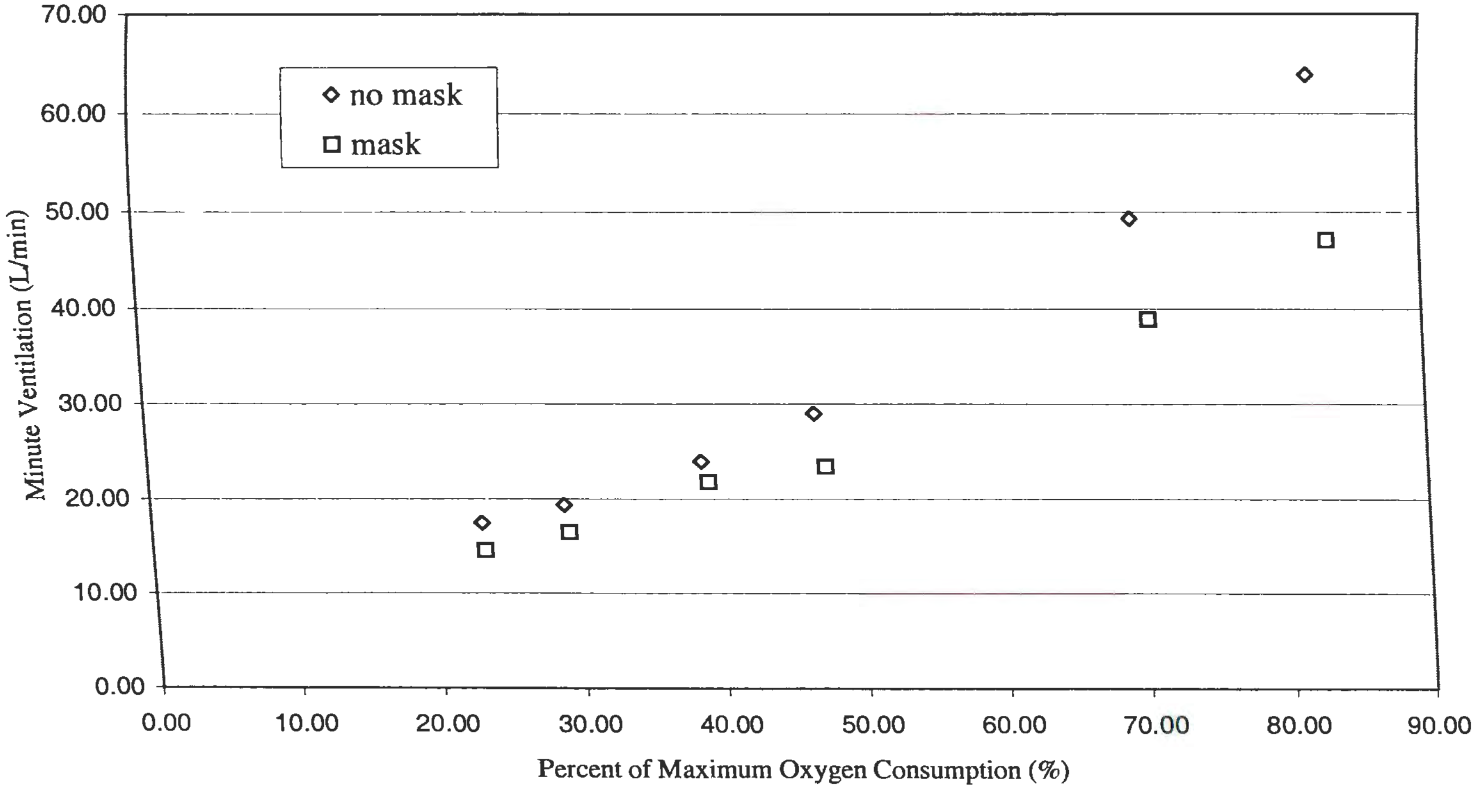

Figure 52. Minute ventilation from model simulation.

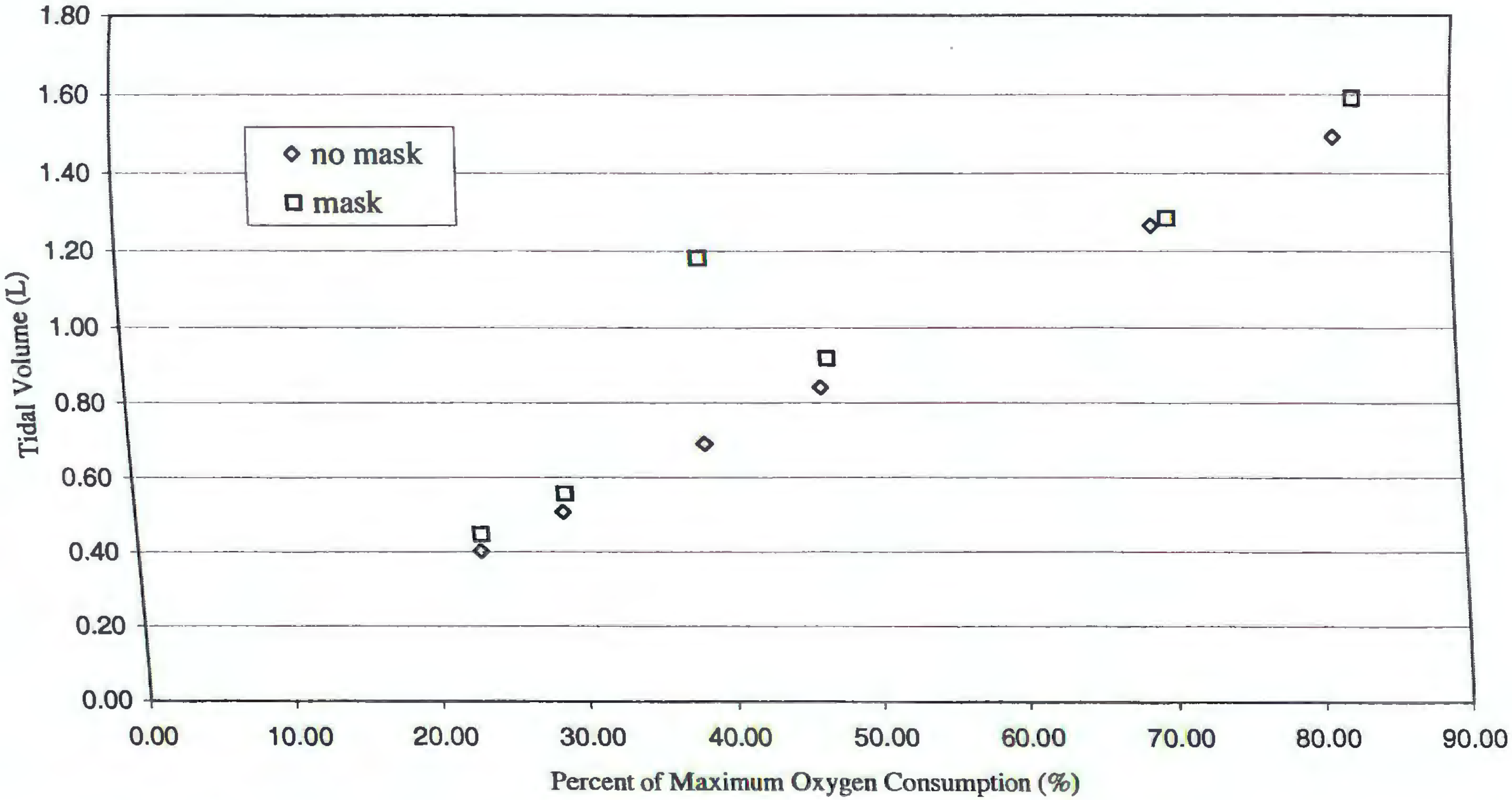

Figure 53. Tidal volume from model simulation.

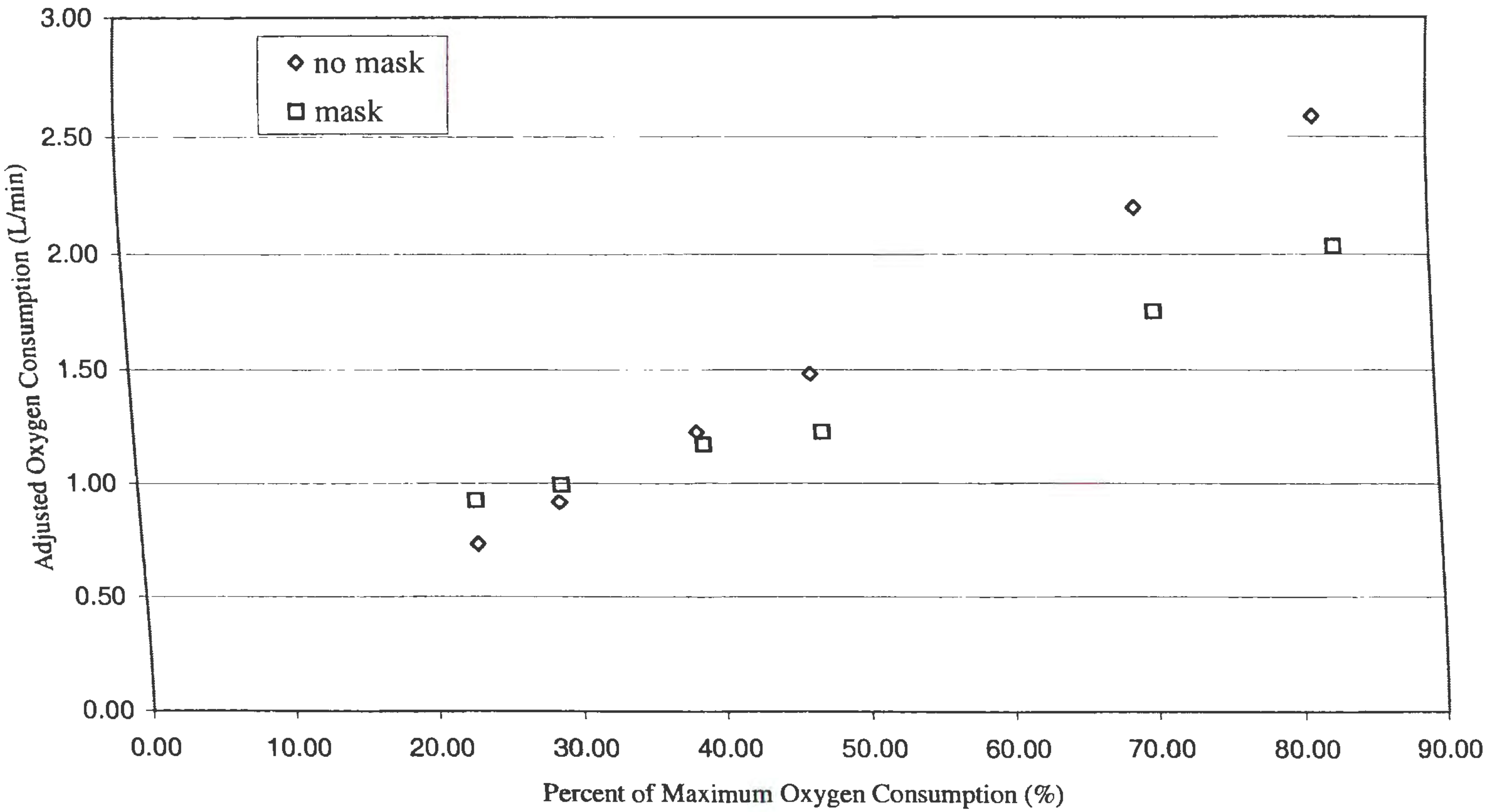

Figure 54. Oxygen consumption from model simulation.

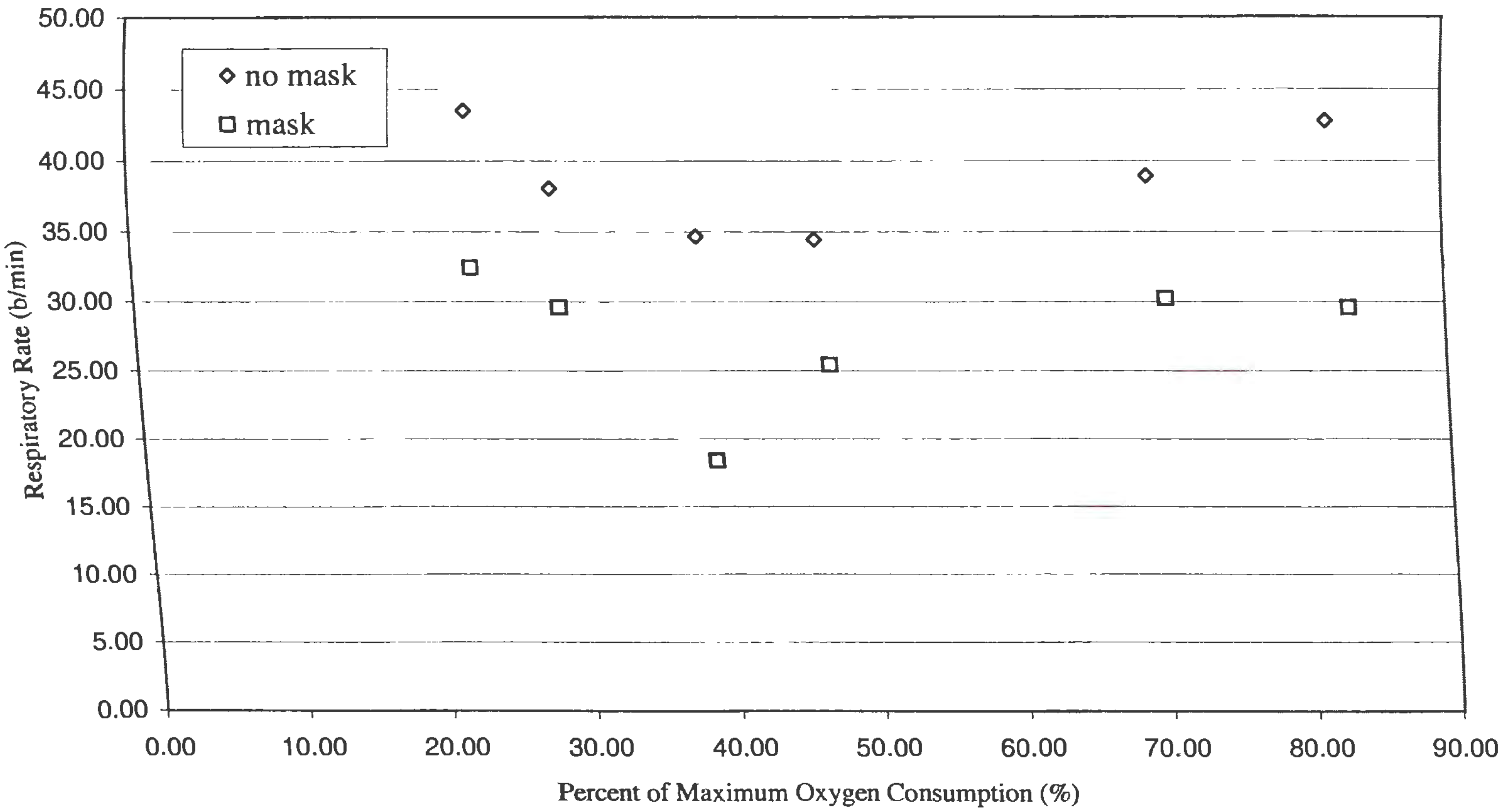

Figure 55. Respiratory rate from model simulation.

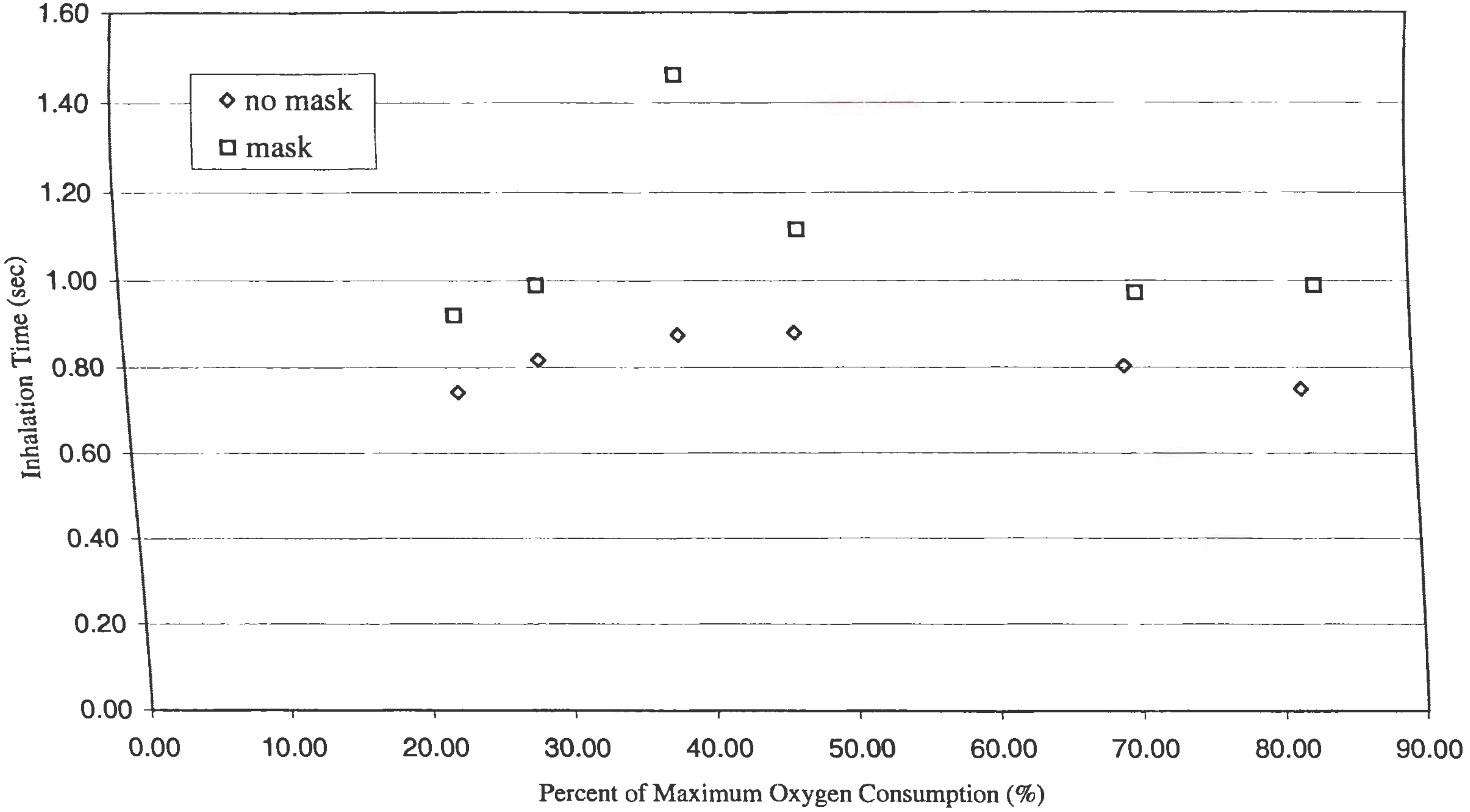

Figure 56. Inhalation time from model simulation.

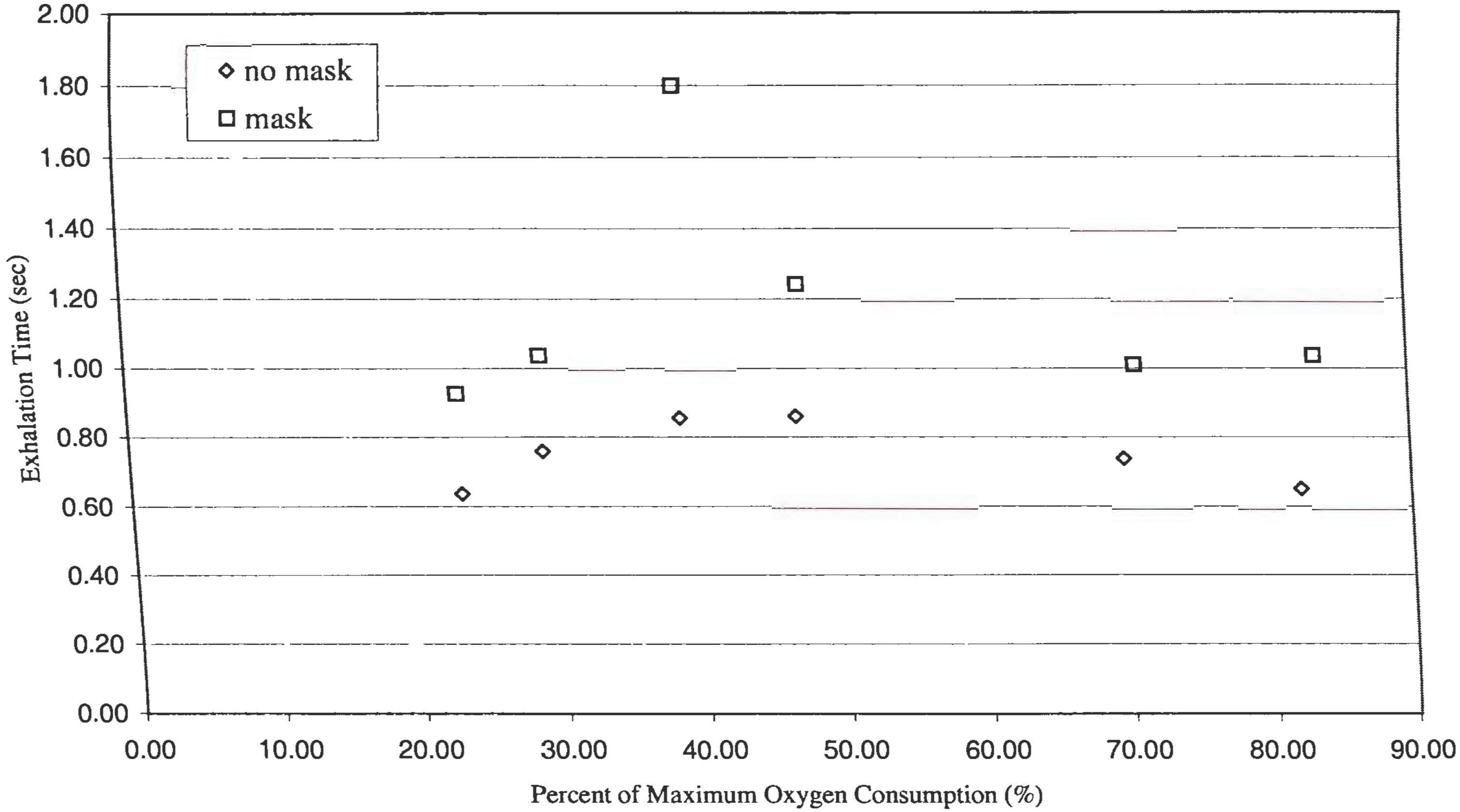

Figure 57. Exhalation time from model simulation.

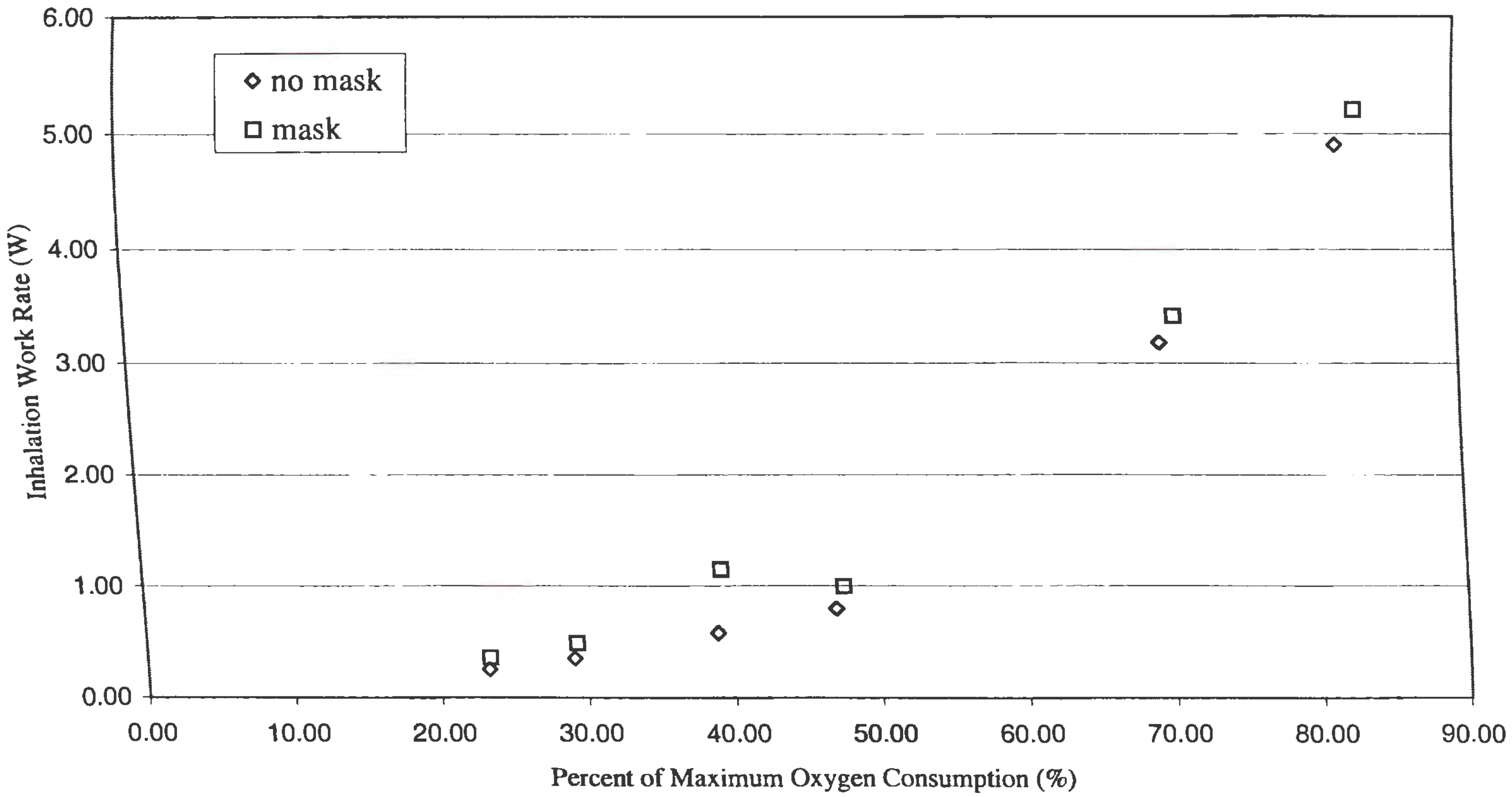

Figure 58. Inspiratory work rate from model simulation.

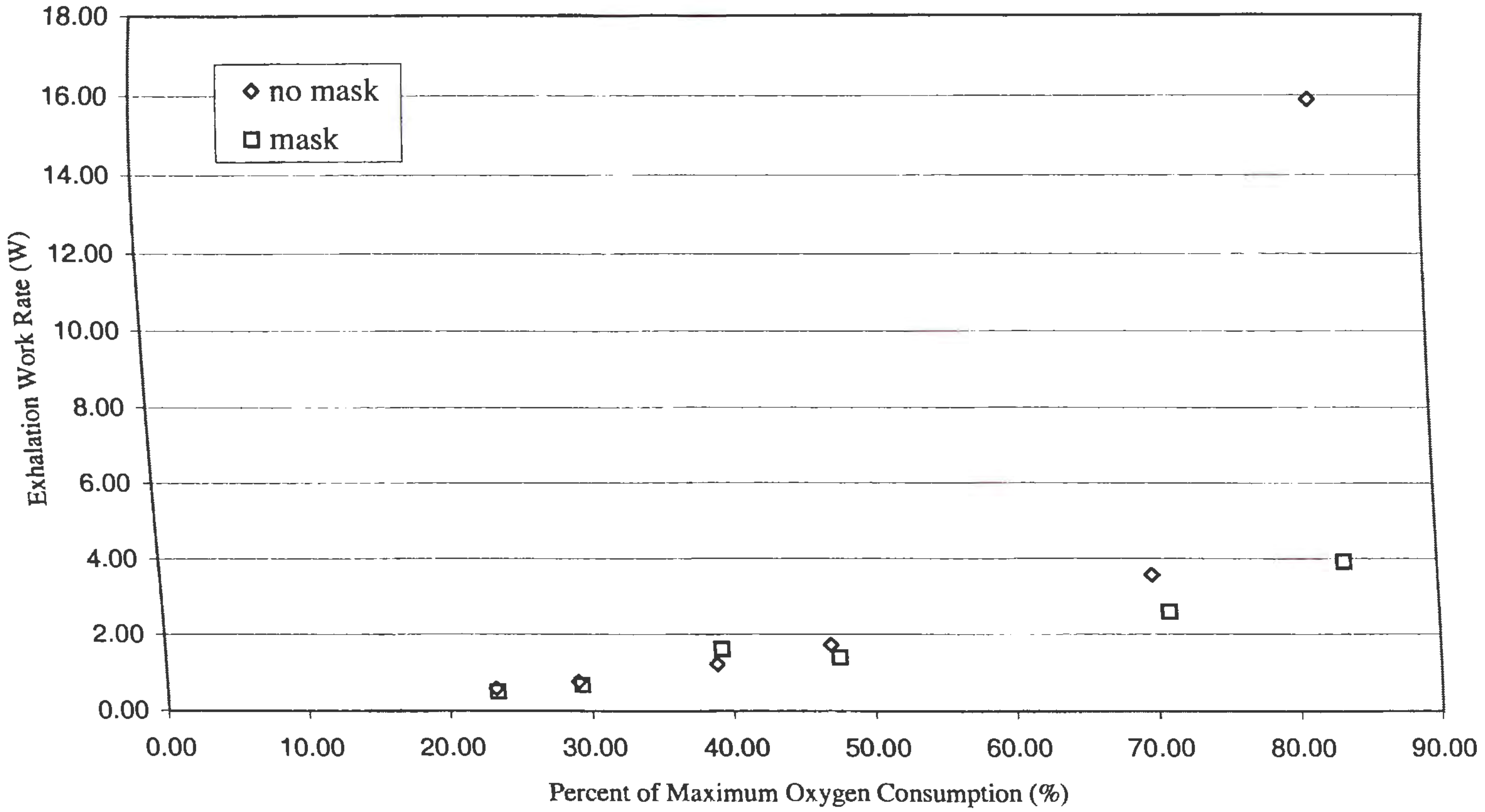

Figure 59. Expiratory work rate from model simulation.

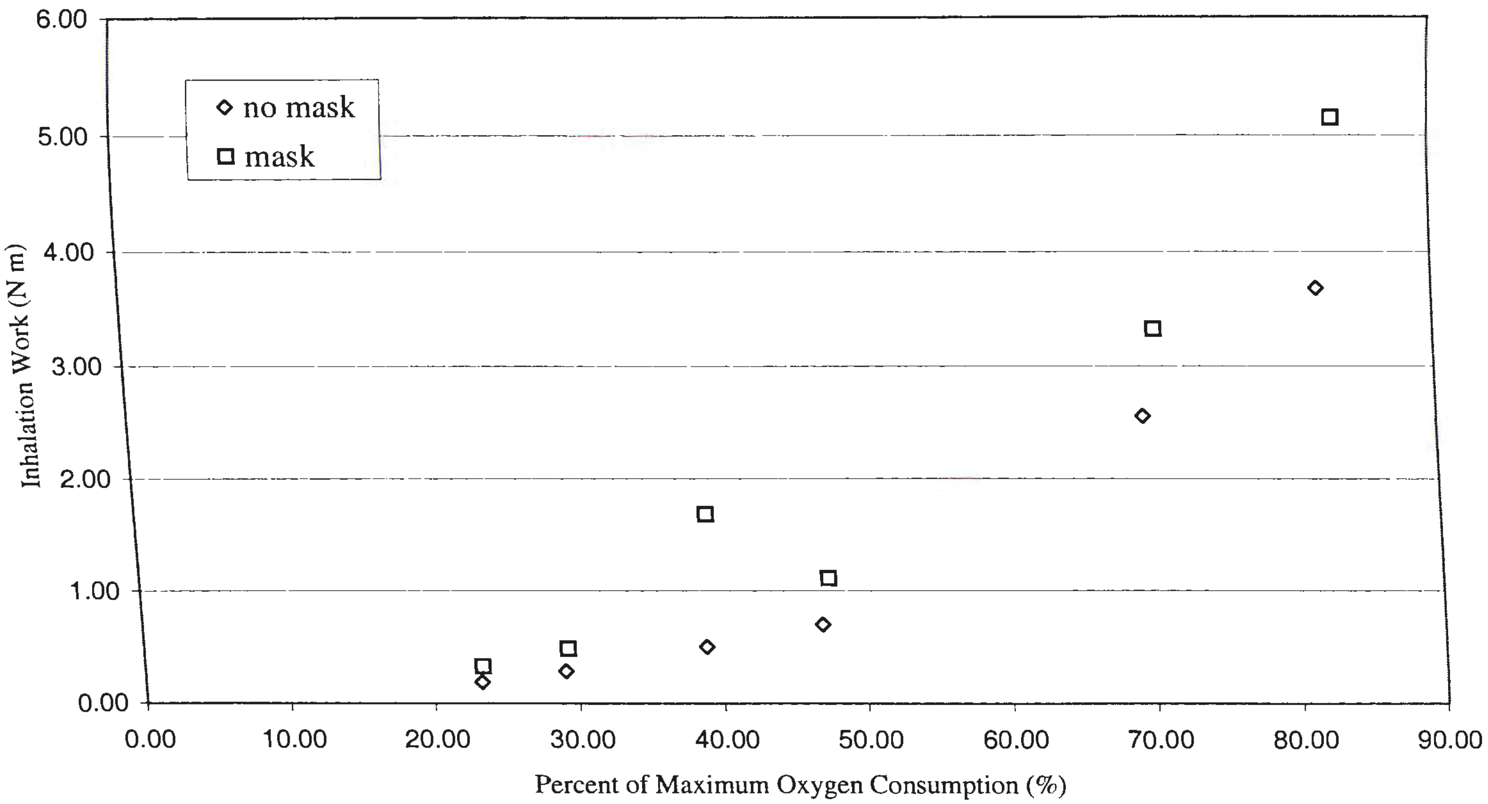

Figure 60. Inspiratory work from model simulation.

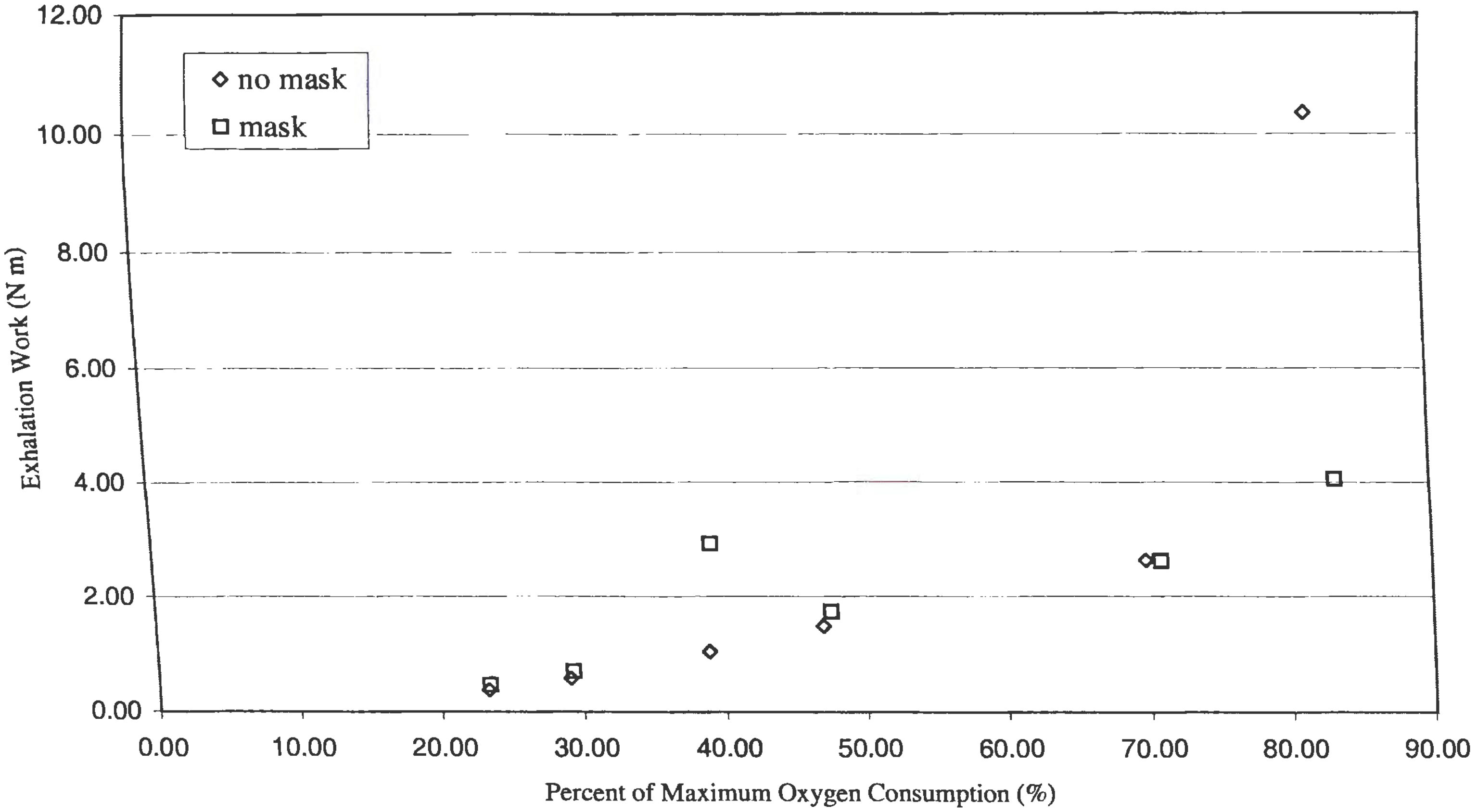

Figure 61. Expiratory work from model simulation.

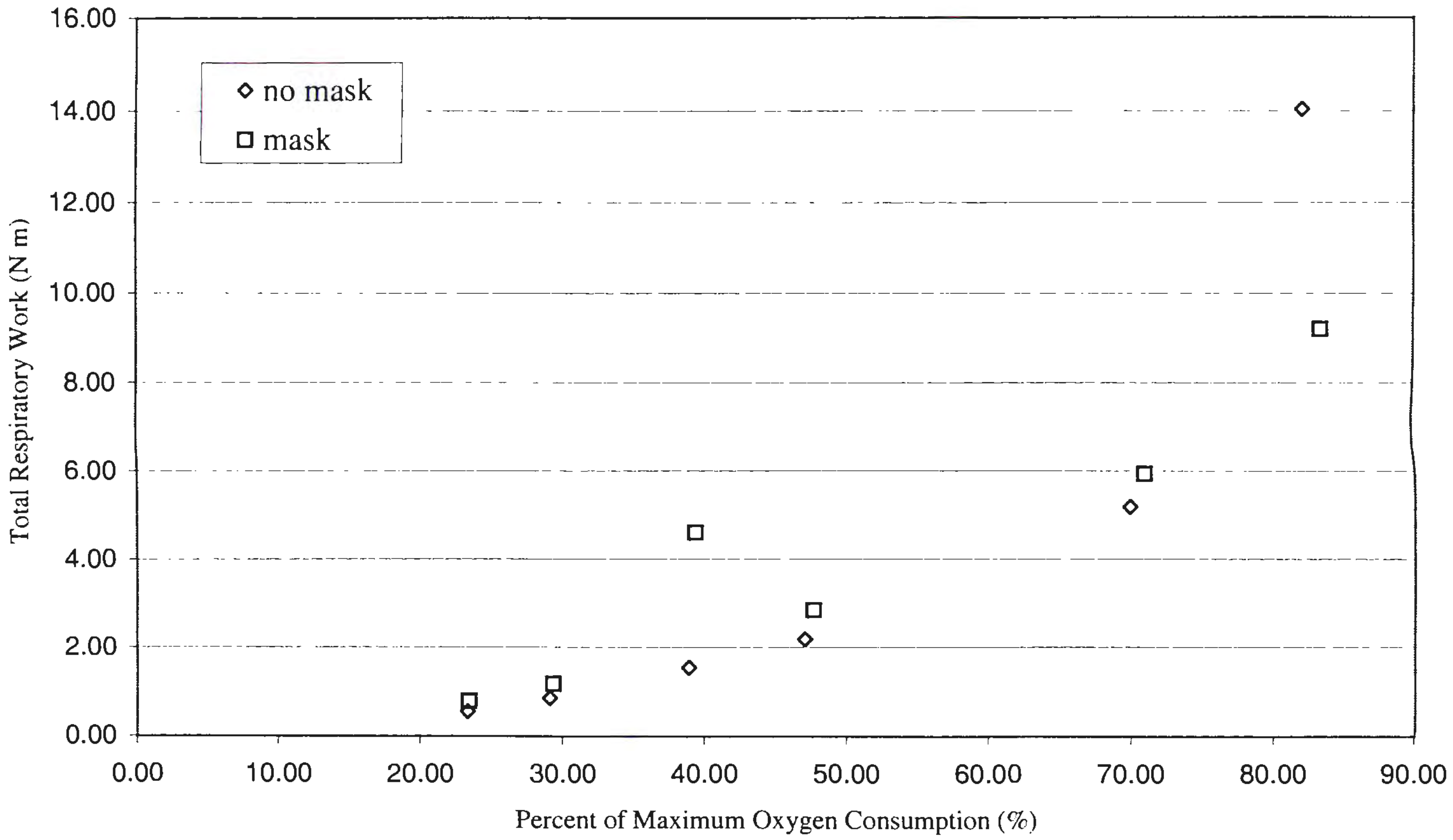

Figure 62. Total respiratory work from model simulation.

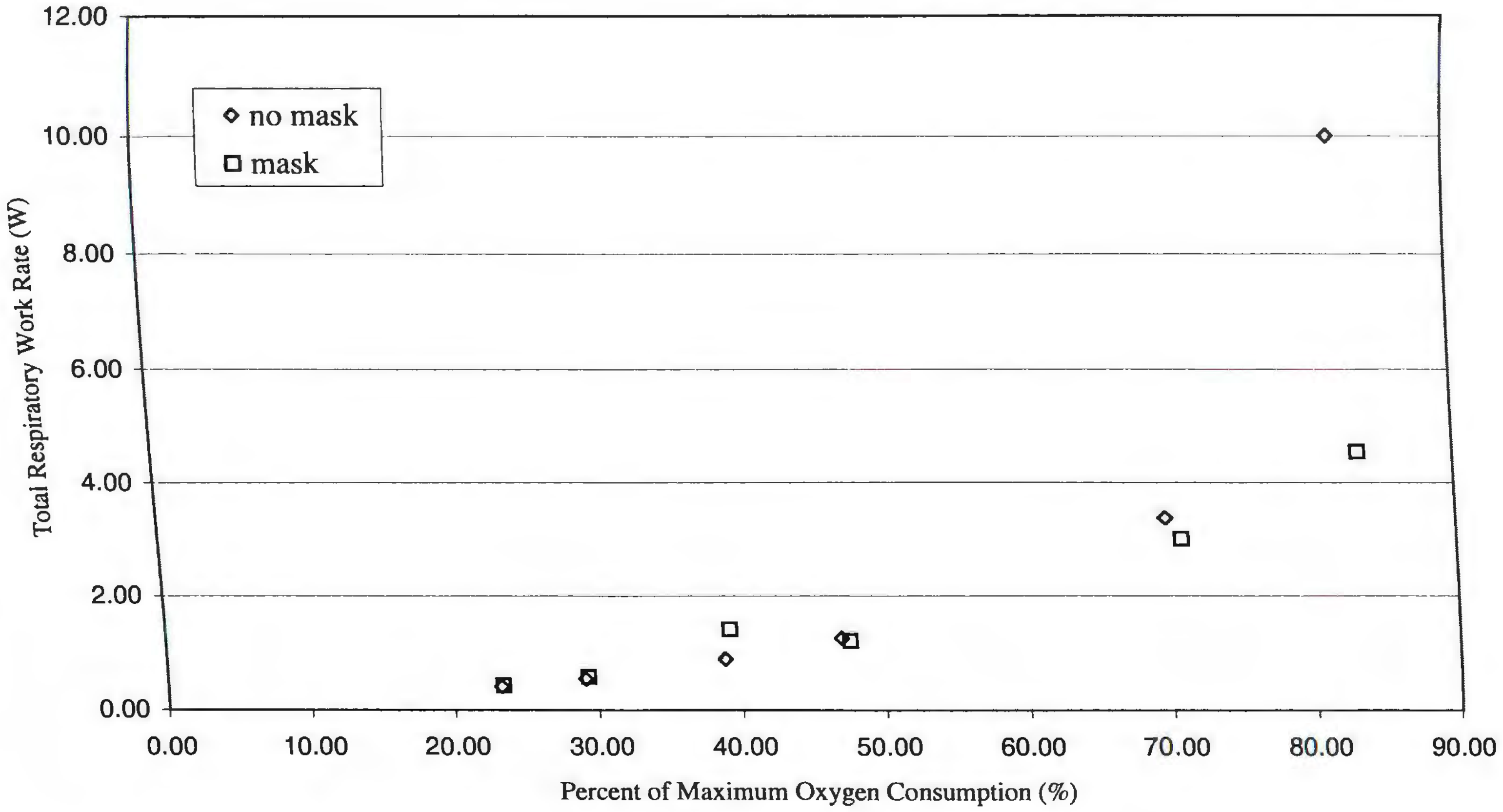

Figure 63. Total respiratory work rate from model simulation.

The model simulation of the no mask condition will be discussed first (see Appendix C, Table 69 for the simulation data). As work rate increased, physiological work rate, required oxygen consumption, minute ventilation, and tidal volume increased, as expected. The increased physiological work rate was due to the added mass of the respirator. The general shapes of the minute ventilation and tidal volume curves were similar to curves of the average values seen for the levels determination session of the current study.

The minute ventilation of 17.5 L/min was higher than expected for a person at rest. Resting minute ventilation is typically around 6 L/min (Johnson, 1991). However, the subjects in the current study frequently had resting minute ventilations of 10 to 18 L/min.

Respiratory rate decreased and then increased as work rate increased. This effect was seen also for the average respiratory rate obtained during the levels determination session of the current study. During the levels determination session, as work rate increased from stages one to two and stages two to three, the percentage changes in tidal volume were greater than the percentage changes in minute ventilation. This caused the decrease in respiratory rate. From stage three to four and four to five, the percentage changes in minute ventilation were much higher than the changes in tidal volume, resulting in an increase in the respiration rate. The pattern of the respiratory rate seen here is contrary to that shown in the literature. Silverman et al. (1951), Harber et al. (1984), and Hermansen et al. (1972) showed that for constant-rate exercise, respiratory rate increased as work rate increased. The model behavior is a result of the data to which the curves were fit. Possible reasons for the discrepancy could be the small sample size or incorrect determinations of steady-state values. Care was taken to ensure that the steady-state values were accurate. While minute ventilation and oxygen consumption values were typically steady, tidal volume fluctuated particularly at low work rates. The fluctuations are likely due to the fact that there is more voluntary control of breathing at the lower work rates. The tidal volume data from the current study were averaged over three minutes, which should have decreased the impact of a single large or small breath. However, if large changes in tidal volume occurred throughout the three-minute sample, then the average value would be affected.

Inhalation and exhalation times increased and then decreased as work rate increased. This was a result of the pattern for respiratory rate. Higher respiratory rates are associated with shorter inhalation and exhalation times. As respiratory rate decreases, the inhalation and exhalation times lengthen.

Respiratory work rate increased as the physiological work rate increased. This was true even with the shortened inhalation and exhalation times at rest in part because the respiratory waveform was chosen based on the work rate and not the inhalation and exhalation times (except for the flow limited case). Using the values for respiratory work rate and inhalation and exhalation times given in Johnson (1993), the total respiratory work for a resting subject with sinusoidal inhalation and hybrid exponential exhalation was 0.62 N·m. The current model predicts total respiratory work of 0.56 N·m for a resting subject. As the parameters (minute ventilation, inhalation and exhalation times) in the Johnson (1993) model were hypothetical, direct comparisons cannot be made. However, the respiratory work predicted by the current model is of the right magnitude. The total respiratory work rate predicted by Johnson (1993) was 0.14 W which is much lower than the 0.40 W predicted by the current model. This is due to the short exhalation and inhalation times predicted by the current model. The large jump in total respiratory work rate at the highest work rate is due to the limited-flow exponential waveform. The exhalation time is below 0.66, so the limited-flow waveform was used. As shown by Johnson (1993), exhaling with this waveform resulted in a much higher work rate compared with other waveforms.

When simulations were run with a masked subject, the minute ventilation decreased at all work rates. (See Appendix C, Table 70 for the simulation data.) This effect has been shown in previous studies (Flook and Kelman, 1973; Silverman et al., 1951; Hermansen et al., 1972; Cerretelli et al., 1969; Caretti and Whitley, 1998; Johnson et al., 1999; Caretti et al., 2001). At rest and for work rates one and four there were small changes in tidal volume. At rest and work rate one, the tidal volume was increased due to dead volume. At stage four, the increase was due to the increased physiological work rate and required oxygen consumption caused by the respirator mass. The second work rate showed a large increase in the tidal volume. This was due to a combination of the resistance and dead volume. Flook and Kelman (1973), Silverman et al. (1951), and Hermansen et al. (1972) showed increases in tidal volume due to resistance at low work rates. Dead volume was shown to increase tidal volume during light exercise (Stannard and Russ, 1948). For the third work rate, the small increase in tidal volume was due to the increase in dead volume compared to the no mask condition. The increased tidal volume at the fifth work rate was due to the resistance. The regression equation obtained for the resistance effects on tidal volume for the current study had a positive slope for exhalation resistance and a negative slope for inhalation resistance. As the magnitude of the exhalation slope was larger than the magnitude of the inhalation slope, the tidal volume increased over the no mask condition. Silverman et al. (1951) and Hermansen et al. (1972) found that tidal volume decreased at high work rates while Caretti and Whitley (1998) found no effect of resistance on tidal volume at high work rates. The results of the current study conflict with these results. Tidal volume did not fluctuate as much during the high work rates as it did during the low work rates, so that should not be a problem with the current data. Caretti and Whitley (1998) adjusted the external work rate for each respirator condition so that the subject was at 80-85% V_{O2max} for each test. It is possible that an increase in tidal volume due to the increased external work rate was offset by a decrease in tidal volume due to the resistance. Small sample sizes may be a problem as well. Eight subjects and three resistance combinations were used in the current study. Silverman et al. (1951) and Hermansen et al. (1972) both used two resistance combinations. Perhaps the true effect of resistance at high work rates was not seen in either the two published studies or in the current study.

Adjusted oxygen consumption increased at rest and work rate one. Decreases in the adjusted oxygen consumption occurred for the higher work rates. The increases at rest and the lowest work rate could be due to the different methods used to calculate minute ventilation from oxygen consumption and adjusted oxygen consumption from adjusted minute ventilation. As minute ventilation is decreased, the oxygen consumption should decrease also. The determination of minute ventilation from oxygen consumption was based on the maximum minute ventilation and the percentage of maximum minute ventilation. Adjusted oxygen consumption was based only on adjusted minute ventilation. As the correlation coefficients for both methods were not one, there were errors associated with the use of each method. The increase in oxygen consumption may be a result of these errors.

The decreased oxygen consumption at the higher work rates was due to the effects of resistance. Oxygen consumption has been shown to decrease as resistance was increased (Johnson et al., 1999; Caretti et al., 2001; Flook and Kelman, 1973; Silverman et al., 1951; Harber et al.,1984).

Respiratory rate for the mask simulation at each work rate is lower than the respiratory rate for the no mask condition. Inhalation and exhalation times were longer with the mask than without at all work rates. This is to be expected. Resistive loading increases inhalation and exhalation times and decreases the respiratory rate (Johnson, 1991). This effect was seen in studies investigating the effects of resistance on breathing parameters (Flook and Kelman, 1973; Silverman et al., 1951; Harber et al., 1984; Hermansen et al., 1972).

Inhalation work was always higher with the mask than without. Exhalation work was higher with the mask up to the fourth work rate. At the fourth work rate, the exhalation work was nearly the same for the masked and unmasked conditions.

The minute ventilation during stage four with the mask is much lower than the minute ventilation without the mask. The components of the work equation are a function of the maximum flow rate that in turn is a function of the minute ventilation. Because the minute ventilation is lower with the mask, the maximum flow is much lower with the mask. This results in a decreased amount of work. Respiratory work should increase when a mask is worn (Johnson, 1992). The error here is likely related to the fact that minute ventilation has been shown to be underpredicted by the current model at high work rates for the respirator condition. A higher minute ventilation would result in a higher amount of work being performed.

At the fifth work rate, the exhalation work rate was much higher without the mask because the flow-limited waveform was used. The flow-limited waveform was used whenever the exhalation time fell below 0.66 sec (Johnson and Berlin, 1974). The mask caused the exhalation time to increase above 0.66 sec for the fifth work rate and the flow-limited waveform was not used for the mask condition. The work of inhalation and exhalation were discussed here because the work rate is affected by the inhalation and exhalation times.

Summary of Model Evaluation

The evaluation of the model showed that for three subjects exercising below 70% V_{O2max}, the model predicted oxygen consumption, tidal volume, and minute ventilation for both respirator and no respirator conditions with the majority of the errors in the range of –32 to 21%. The percentage errors for these subjects were in the same ranges as the errors for the individual equations. However, for three subjects working at 80-85% V_{O2max} while wearing respirators, the percentage errors for oxygen consumption, minute ventilation, and tidal volume were greater than those of the original equations. These errors may result from the fact that the model equations were developed for average responses. Thus, predictions for any one person may have large errors. The comparison of masked to no mask results from model simulations showed that overall the model made rational predictions of the effects of respirator wear. Minute ventilation and respiratory rate were lower with the mask than without. Inhalation and exhalation times and inhalation and exhalation work were higher with the respirator, as was expected.

Many of the equations developed in the model were based on small populations because additional data was not available. One of the benefits of this model was that it showed areas where more information is needed.

At the start of this modeling project, it was not known whether or not the selected structure would be functional. Many simplifications were made in developing this model. While prediction accuracy for individuals was less than that for averages, this was to be expected as the equations in the model were based on average responses. Results of this analysis showed that the model structure was valid and that the model was capable of making rational predictions of the average effects of respirator wear on the pulmonary system during physical activity.

CONCLUSIONS

The conclusions that may be drawn from this research were:

1. The model of the pulmonary effects of respiratory protective masks during physical activity was implemented successfully.

2. For three subjects exercising below 70% of V_{O2max} with and without a respirator, 81% of the model prediction errors were in the range –32 to 21%. These errors were of the same magnitude as those of the original equations.

3. Model prediction errors for three subjects wearing a respirator while exercising at 80-85% of V_{O2max} were greater than the errors of the model equations.

4. The model did well at making general predictions but did not predict well for an individual.

5. Overall, the model made rational predictions of the effects of respirator and no respirator conditions for rest and exercise up to 80-85% of V_{O2max} during simulations.

6. The model was implemented successfully as a design tool that enabled the user to assess the pulmonary effects of a respirator on a person performing a physical activity.

7. The program that made up the design tool was structured so that future development of the model could be integrated easily.

SUGGESTIONS FOR FURTHER STUDY

1. An experimental study should be conducted that investigates the effects of a large number of resistance and dead volume combinations on a large number of subjects working over a broad range of constant work rates from rest to maximal exercise. This information could be used to further assess the accuracy of the model equations and the overall model.

2. Better methods of predicting oxygen consumption based on external work rate for various activities should be investigated.

3. The existing model should be developed to include effects of training, age, gender, and anxiety on all equations.

4. The literature should be examined, and, if necessary, an experiment conducted to determine the maximal oxygen deficit.

5. Equations should be developed to include transient effects in the model. Transient effects should include the initial changes in pulmonary parameters as activity begins as well as changes due to factors such as oxygen drift and the slow component of oxygen consumption.

6. The equations for respiratory work rate should be developed further to include the effects of frequency and volume on the model parameters.

APPENDICES

Appendix A Human Subjects Protocol

Dept ____
IRB ____
INV _X_

HUMAN SUBJECTS APPLICATION COVER SHEET

Principal Investigator's Name: Karen M. Coyne / Arthur T. Johnson, PhD Date 14FEB01

Address: Dept. of Biological Res. Eng, Univ. of MD, College Park, MD 20742 (Zip Code)

Home Phone: 410-675-4578 Campus Phone: 5-1186/5-1184 Email: kmkcoyne@wam

Advisor's Signature (required if thesis or dissertation): Arthur T. Johnson

PROJECT TITLE: The effects of resistance on the relationship between tidal volume, minute volume, and oxygen consumption during steady-state exercise

Type of Research:
- ____ Undergraduate Thesis (KNES 497)
- _✓_ Graduate Project/Thesis/Dissertation
- ____ Other

Review Request:
- ____ Req. For Exemption (see p. 5)
- _✓_ Non-Exempt

____ Funded: ______________ (Name of Agency)
_✓_ Non - Funded
____ Involves exercise testing/training (See KNES Protocol Document)

Frequency of Data Collection:
- _✓_ One time/single research study
- ____ Data collection procedures to be repeated periodically as part of several studies. Time period requested is maximum of three (3) years.

Instructions: Submit the following to the chairperson of the Committee for Research on Human Subjects. (Please provide four (4) copies of Nos. 1, 2, 3 listed below.)

1. **Cover Sheet**
2. **Description and Response to Six Questions (with requested attachments)**
3. **Request for Exemption** - submit if applicable
4. **Copy of Research Proposal** - if M.A. thesis or Ph.D. dissertation (one copy)

Action by Department of Kinesiology Human Subjects Research Committee (HSRC):

____ Accept _X_ Accept **w/ Revisions** ____ Reject

Comments:

____

Department of Kinesiology
Human Subjects Review Committee (HSRC)

Approved: M.A. Rogers, 2-19-01
(Chairperson) (Date)

[Approval valid for one (1) year only.]

Rev 3/2000

DESCRIPTION OF HUMAN SUBJECTS USE

Principal Investigator: Karen M. Coyne / Arthur T. Johnson, Ph.D.
Graduate Student / Professor
Department of Biological Resources Engineering
University of Maryland
College Park, MD 20742
(301) 405 – 1184

Associate Investigators: William H. Scott, M.A.
Department of Biological Resources Engineering
University of Maryland
College Park, MD 20742
(301) 405 – 1199

Project Title: The effects of resistance on the relationship between tidal volume, minute volume, and oxygen consumption during steady state exercise

A. Subject Selection

1) Who will be the subjects? How and from where will they be obtained? If you plan to advertise for the subjects, include a copy of the notice.

Between 5 and 10 subjects will be selected for participation in this study. Subjects will be selected from an existing pool of individuals who have participated in other projects conducted in our laboratory on the campus of the University of Maryland College Park.

2) Are the subjects being selected for any specific characteristics, e.g., age, sex, race, ethnic origin, religion, or any social or economic qualifications?

Individuals (both male and female) between the ages of 18 to 39 years of age will be selected to participate in this investigation. Within this age range, only those individuals who are apparently healthy and are free of coronary risk factors, as determined by completion of a medical history questionnaire and the PAR-Q, will be considered for study participation. In addition, prospective subjects who score above 45 on the Spielberger Trait Anxiety Inventory (The State-Trait Anxiety Inventory. Palo Alto, CA, Consulting Psychologist Press, 1983) will be excluded from study participation due to the possibility of exhibiting anxiety while wearing a respirator.

3) State why the selection is made on the basis given in (2).

The intent of this study is to quantify the relationship between tidal volume, minute volume and oxygen consumption during steady-state exercise and to determine the effects of resistance on this relationship. In order to do this, subjects will be asked to complete treadmill exercise at intensities up to 80% of a subject's maximal oxygen consumption. The American College of Sports Medicine (ACSM) recommends that apparently healthy individuals below the age of 40 can begin such a vigorous exercise program without obtaining medical clearance. Since medical clearance will not be provided to any prospective subjects, selected subjects will be categorized as stated above to conform to the ACSM guidelines. In addition, only individuals free of cardiorespiratory disease can participate in studies that represent a substantial challenge and result in significant increases in heart rate and respiration. The fitness level of the selected subjects will not be considered to be a major factor because each subject will serve as their own control and relative levels of maximal oxygen consumption will be used for testing. The Trait Anxiety Inventory (TANX) is a measure of individual differences in anxiety proneness. High TNAX scores have been shown to be a predictor of respiratory distress during respirator wear combined with heavy exercise (Am. Ind. Hyg. Assoc. J. 46:363-368, 1985).

B. What precisely will be done to the subjects? Explain in detail your methods and procedures in terms of what will be done to the subjects.

Orientation

All prospective subjects will be required to complete a detailed medical history questionnaire and the PAR-Q. An investigator will meet with each subject to review and discuss information contained in the questionnaires. Prospective subjects will also complete the Spielberger TANX to assess general anxiety. Subjects with acceptable medical histories and TANX scores will be given an informed consent document to review. This document describes the methods and procedures that the subject will be asked to perform in the study. Each volunteer will receive a verbal explanation of the points covered by the informed consent document and will be given every opportunity to discuss concerns or questions regarding their participation before being asked to sign the document. All subjects will sign the informed consent document before any test session begins.

Pre-test Measurement of Maximal Oxygen Consumption

Prior to commencement of test trials, each subject will complete a test to determine maximal oxygen consumption (VO_{2max}) using a standard protocol (Guidelines for Exercise Testing and Prescription, 2000) on a treadmill. Throughout the test, subjects will don a nose-clip and breathe through a mouthpiece while all ventilatory and metabolic measurements are obtained. The criteria for test termination when measuring VO_{2max} include a change of less than 200 ml/min of oxygen uptake with increasing workload, a respiratory exchange ratio of greater than 1.0, achievement of maximal predicted heart rate, and/or a rating of perceived exertion (RPE) greater than 17 (very hard). Subjects can voluntarily terminate the test at any time. Heart rate, ECG, RPE, and blood pressure will be monitored during VO_{2max} testing. Abnormal exercise responses observed for any of these measurements will result in termination of testing before a maximal level of effort has been attained. Subjects who exhibit an abnormal blood pressure response will be noted. These subjects will have their blood pressure monitored during the three submaximal walking tests. Laboratory personnel experienced with the administration and interpretation of VO_{2max} tests will be present for all testing. Personnel who have received CPR training and who are aware of the procedures that must be followed to initiate emergency response will also be present for all VO_{2max} tests.

Treatment Sessions

There will be three conditions of submaximal exercise testing that will be randomly assigned and will occur on separate days. Exercise for each condition will involve submaximal, constant load treadmill exercise at five intensity levels: 25-30%, 35-40%, 45-50%, 65-70%, and 80-85% of VO_{2max} while wearing one of three respirators. The three respirators are: full-facepiece respirator with inhalation and exhalation valves removed (nominal resistance), full-facepiece respirator with inhalation and exhalation resistances of 1.84 and 1.69 $cmH_2O/L/s$, and full-facepiece respirator with inhalation and exhalation resistance of 5.73 and 1.01 $cmH_2O/L/s$. Prior to the commencement of each treatment session, subjects will complete a five-minute warm-up period of treadmill walking. The treadmill will then be stopped momentarily so the subject can don the test respirator. Once the respirator is in place, subjects will begin exercising at 25-30% of VO_{2max}. After a steady state is achieved, the exercise intensity will be increased to 35-40% of VO_{2max}. This will continue with intensity increasing sequentially to 45-50%, 65-70%, and 80-85% of VO_{2max}. Testing will continue until one of the following events occurs: steady-state has been reached at each exercise intensity; a subject requests to terminate the procedure or is unable to continue; heart rate reaches maximal rate recorded during VO_{2max} testing; the principal investigator determines that continued participation in the test would threaten the volunteer's safety; or the monitoring equipment is unable to provide adequate measurements or fails. These treatment sessions will occur after the initial VO_{2max} session.

The following cardiorespiratory and subjective parameters will be monitored during each testing session: heart rate, ECG, tidal volume, minute volume, oxygen consumption, RPE, breathing apparatus comfort, and thermal sensation. The State-Anxiety test, a measure of situational anxiety, will be administered before and after each treatment session. All testing procedures will be conducted at ambient room temperature (74°F) in an environmentally controlled laboratory to minimize environmental influences on the data. Each subject will be instructed to get adequate rest the night before each test, to eat breakfast or lunch, and to drink plenty of fluids, excluding alcohol and caffeine, before reporting to the laboratory. Volunteers will be clothed in T-shirts, shorts, socks, and sneakers for all exercise trials.

C. Are there any specific risks to the subjects? If so, what are the risks? What potential benefits will accrue to the subjects to justify these risks?

The procedures and circumstances encompassed by this protocol provide for a high degree of safety. The performance of any exercise can entail the potential hazards of injury from overexertion and/or accident. The possibility of cardiopulmonary overexertion is slight; screening (via the medical history questionnaire and the PAR-Q), selection, and monitoring procedures that are designed to anticipate and exclude the rare individual for whom exercise might be harmful will minimize its chance for occurrence.

All testing procedures will be administered in the presence of laboratory personnel certified in cardiopulmonary resuscitation. All investigators are experienced in administering exercise stress tests. The principal investigator and/or one of his associates will be present during all facets of data collection. Immediately prior to testing, an investigator will question each volunteer to insure that no apparent condition exists in the volunteer that would jeopardize his/her safety or health. Examples of such conditions would be an upper respiratory tract infection, excessive fatigue, musculoskeletal injuries, recent excessive use of alcohol, taking of medications that would adversely interact with increased metabolic activity, or other illness that may negatively affect the ability to exercise or compromise subject safety. Individuals who report to have or appear to have any such conditions will not be allowed to participate in testing on that particular day. Such volunteers will be rescheduled for testing at another time once they have fully recovered from their ailment. The monitoring of vital signs (e.g., heart rate, ECG, RPE, etc.) will ensure that the investigators are aware of the individual's exercise responses and will be used to determine whether or not an exercise session should be terminated prematurely. Blood pressure will be monitored during the three submaximal walking tests for any subject that had an abnormal blood pressure response during the maximal exercise test.

Accidents may result in bodily injury during physical activity. The risk of this is far less during the completely supervised activities used in a research study than in unsupervised exercise or competitive sports. Safeguards will be taken whenever the possibility exists that the volunteer may have difficulty in bodily control or balance.

There is a slight chance for transmission of viral infections from one subject to the next due to repeated use of the test respirators between test volunteers. This risk will be minimized because all respirators will be cleaned with sanitary respirator wipes or alcohol pads before and after each use.

Some individuals may experience minor skin irritations as a result of the procedures used to obtain heart rates and ECG recordings. This condition is commonly resolved within a short period of time.

No direct benefits are expected for the volunteers participating in this study. Subjects will receive a copy of their VO_{2max} test results so that they may compare their fitness levels with others such as athletes whose VO_{2max} values are often published in magazines or journals.

D. Generally, anonymity of the subjects must be preserved. What procedures will be used to insure anonymity?

Subjects are assured anonymity as participants in this investigation. Subjects will be assigned identification numbers and will be referred to by this number during data acquisition and analysis. Information pertaining to the subjects will be accessible only by individuals involved with the conduct of this study. All subject records and medical information will be considered privileged and will be held in confidence. Subjects will not be personally identified in any presentation or publication of the results of this study.

E. State specifically what information will be provided to the subject about the investigation. State how the subject's consent will be obtained.

Each subject will read and sign an informed consent that describes in detail the nature of the study and the specific methods and procedures that will be administered at each test session. Each volunteer will receive a verbal explanation of the points covered by the informed consent document and will be given every opportunity to discuss concerns or questions regarding their participation before being asked to sign the document. An investigator will ensure that subjects understand that their participation in this study is voluntary and that they are free to withdraw from participation at any time without fear of penalty. Withdrawal requests may be made to any investigator either orally or through written documentation. All subjects will sign the informed consent document before any testing sessions begin.

F. Where will the study be conducted?

This study will be administered in the Biological Resources Engineering Department's Human Performance Laboratory (room 0534 in the Agricultural Engineering Building) on the University of Maryland, College Park, MD campus.

Consent Form

Title: The effects of resistance on the relationship between tidal volume, minute volume, and oxygen consumption during steady state exercise

I, ____, state that I am between the ages of 18 and 39 years old and wish to participate in a project being conducted by Arthur Johnson, Ph.D., Karen Coyne, and William Scott of the University of Maryland's Biological Resources Engineering Department on the College Park campus. The purpose of this study is to assess the effects of breathing resistance on the relationship between the volume of air exhaled with each breath, the volume of air respired during one minute, and oxygen consumption. The data to be obtained from this study will help to quantify the relationships.

I understand that, prior to participation in this study, I will report to the laboratory for an orientation session that will last approximately 30 minutes. At this session, this informed consent, which describes the procedures, methods, and individual subject rights for this study, will be given to me for my review. I understand that I will be asked to complete a medical history questionnaire that details my medical history. I understand that I will be asked to complete a PAR-Q questionnaire that will assess my ability to participate in physical activity. I understand that I will also be asked to complete a computer-administered survey that will be used to rate my general level of anxiety. I understand that this survey is not a reflection of my past or present emotional stability. I understand that an investigator will be present to answer any questions that I may have concerning this investigation and my participation.

I have been informed that on my first visit for testing I will undergo a maximal exercise test. This test will be done on a treadmill and involves exercise that allows work rate to be increased progressively until I become exhausted and decide to end the test or other signs or symptoms dictate the stoppage of this test. I understand that I will probably become exhausted within 9 – 15 minutes during this maximal exercise test. Also, I am aware that this entire session will require about one hour of my time. I understand that my blood pressure, heart rate, rating of perceived exertion, and oxygen consumption will be monitored throughout the maximal exercise test. I understand that performance of any exercise test involves some risk to my heart and lungs, which are potentially life threatening. However, I understand that this risk is minimal for individuals within my age group who have no known symptoms of heart or lung disease. The risk of death during or immediately after an exercise test is less than or equal to 0.01%. The results of my maximal exercise test will be used to assess by cardiorespiratory fitness for study participation and to determine the exercise level that I will be exposed to for subsequent treadmill tests.

I understand that I will be asked to complete three conditions of submaximal treadmill exercise and that these conditions will be randomly assigned and will occur on different test days. These test sessions will involve constant load exercise at intensities of 25-30%, 35-40%, 45-50%, 65-70%, and 80-85% of my maximal exercise capacity while wearing either a full-facepiece mask with varied inspiratory and expiratory breathing resistances. I understand that it may be uncomfortable to breathe when wearing the ~~mask especially when I am~~ exposed to a high level of breathing resistance. I understand that I will exercise at each intensity level until my oxygen consumption has reached a steady-state. I am aware that it may take 3 to 6 minutes to reach a steady-state at each intensity level and that I will be walking on the treadmill for 15 to 30 minutes. I understand that a test administrator will stop a test for medical reasons (e.g., abnormal ECG, heart rate, etc.) or if there is an unforeseen problem with data collection equipment. These three treatment sessions will occur after my initial maximal exercise test session. I understand that each treatment session will require about one hour of my time.

I understand that the following measures will be obtained at various times throughout each test session: heart rate, oxygen consumption, minute volume (the volume of air respired during one minute), tidal volume (the volume of air exhaled with each breath), breathing resistance, rating of perceived exertion, breathing apparatus comfort, and thermal sensation. I understand that my blood pressure may also be taken at various times throughout each test session. I will also be asked to complete the computer-administered State-Anxiety survey, a measure of situational anxiety, before and after each exercise session. I also realize that I will complete a test to assess the level of respiratory resistance that exists within my lungs and air

passages. I have been instructed that this test will require me to use a mouthpiece and a nose-clip and to breathe normally in and out of my mouth while I hold my cheeks with my hands. I understand that several breaths will be analyzed to record my respiratory resistance but that
the test is normally completed within 5 minutes. I understand that all testing procedures will be conducted at ambient room temperature (74°F) in an environmentally controlled laboratory. I have been advised to get adequate rest the night before each test, to eat breakfast or lunch, and to drink plenty of fluids, excluding alcohol and caffeine, before reporting to the laboratory. I understand that I need to bring my own T-shirt, shorts, socks, and sneakers to wear for all trials.

I am aware that I am free to ask questions about this study and withdraw my participation at any time without any penalty. I realize that the University of Maryland does not provide any medical or hospitalization insurance coverage for study participants nor will the University provide compensation for any injury sustained as a direct result of participation in this study except as required by law. I understand that I will be asked about my health status before each test session to insure that I have no condition that would jeopardize my safety or health. I am aware that if I am excessively tired, have any musculoskeletal injury, have recently consumed excessive amounts of alcohol, or report to have a cold I will not be allowed to participate in testing. I understand that if this situation should arise that I will be rescheduled for testing at another time once I have fully recovered from my ailment. I understand that accidents may result in bodily injury during physical activity. However, I am aware that the risk of this is far less during the completely supervised activities used in a research study than in unsupervised exercise or competitive sports. I have been informed that some individuals have experienced minor skin irritations as a result of the procedures used to obtain heart rates. I understand that this condition is commonly resolved within a short period of time.

I understand that any information gathered in this study that pertains to me will be held in the strictest confidence and will not be revealed to anyone that is not directly involved with this investigation. I understand that this study has not been designed for my benefit. I understand that I will not receive any monetary benefits for my participation. However, I will be given information regarding my general fitness level. I understand that I am free to withdraw as a participant without being penalized in any way. I am aware that I may request to withdraw either by word of mouth or in writing. I understand that I must sign this informed consent before I will be allowed to participate in this investigation. I am aware that I will be given a copy of the signed consent form prior to beginning my participation.

Investigators:

Karen Coyne, Arthur Johnson, Ph.D., and William Scott
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Department of Kinesiology
Human Subjects Review Committee (HSRC)

Approved: M A Rogers 2-19-01
Chairperson **Date**

______________________________ ______________
Volunteer's signature Date

______________________________ ______________
Witness's signature Date

(revised 1994)

PAR - Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has you doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of any other reason why you should not do physical activity?

If

you

answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active—begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal—this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever—wait until you feel better; or
- if you are or may be pregnant—talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

You are encouraged to copy the PAR-Q but only if you use the entire form

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

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Société canadienne de physiologie de l'exercice

Supported by: Health Canada Santé Canada

SELF-EVALUATION QUESTIONNAIRE

Developed by Charles D. Spielberger
in collaboration with
R. L. Gorsuch, R. Lushene, P. R. Vagg, and G. A. Jacobs

STAI Form Y-1

Name ______________________________ Date __________ S ___
Age __________ Sex: M ____ F ____ T ___

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then blacken in the appropriate circle to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	①	②	③	④
2. I feel secure	①	②	③	④
3. I am tense	①	②	③	④
4. I feel strained	①	②	③	④
5. I feel at ease	①	②	③	④
6. I feel upset	①	②	③	④
7. I am presently worrying over possible misfortunes	①	②	③	④
8. I feel satisfied	①	②	③	④
9. I feel frightened	①	②	③	④
10. I feel comfortable	①	②	③	④
11. I feel self-confident	①	②	③	④
12. I feel nervous	①	②	③	④
13. I am jittery	①	②	③	④
14. I feel indecisive	①	②	③	④
15. I am relaxed	①	②	③	④
16. I feel content	①	②	③	④
17. I am worried	①	②	③	④
18. I feel confused	①	②	③	④
19. I feel steady	①	②	③	④
20. I feel pleasant	①	②	③	④

SELF-EVALUATION QUESTIONNAIRE

STAI Form Y-2

Name ______________________________ Date ____________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then blacken in the appropriate circle to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	①	②	③	④
22. I feel nervous and restless	①	②	③	④
23. I feel satisfied with myself	①	②	③	④
24. I wish I could be as happy as others seem to be	①	②	③	④
25. I feel like a failure	①	②	③	④
26. I feel rested	①	②	③	④
27. I am "calm, cool, and collected"	①	②	③	④
28. I feel that difficulties are piling up so that I cannot overcome them	①	②	③	④
29. I worry too much over something that really doesn't matter	①	②	③	④
30. I am happy	①	②	③	④
31. I have disturbing thoughts	①	②	③	④
32. I lack self-confidence	①	②	③	④
33. I feel secure	①	②	③	④
34. I make decisions easily	①	②	③	④
35. I feel inadequate	①	②	③	④
36. I am content	①	②	③	④
37. Some unimportant thought runs through my mind and bothers me	①	②	③	④
38. I take disappointments so keenly that I can't put them out of my mind	①	②	③	④
39. I am a steady person	①	②	③	④
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	①	②	③	④

University of Maryland
Health History Questionnaire

Name ______________________ Address ______________________

Phone (day) ______________ (evening) ______________ Age ________

Date of Birth __________ Social Security # ______________ Race ________

Personal Physician ______________ Address ______________________

Office Phone ______________

Marital Status __________ Sex ______ Height ______ Weight ______

Family History

List all ***deceased*** immediate family members (parents, grand parents and brothers/sisters) as well as cause of death and age at death.

____

____

____

____

____

Medications

List any current medications or dietary supplements you may be taking and the reason:

____

____

Allergies (include allergies to medications as well)

____

Personal Health Conditions:

Have you had any of the following? Please circle appropriate response:

high blood pressure	yes	no
heart murmur	yes	no
heart attack	yes	no
stroke	yes	no
diseases of the arteries	yes	no
angina	yes	no
rheumatic fever, scarlet fever	yes	no
thyroid disease	yes	no
emphysema	yes	no
diabetes	yes	no
bronchitis, pneumonia	yes	no
yellow jaundice	yes	no
hepatitis	yes	no
kidney disease	yes	no
depression	yes	no
arthritis	yes	no
tuberculosis	yes	no
epilepsy	yes	no
asthma	yes	no
leukemia	yes	no
cancer	yes	no
glaucoma	yes	no
elevated cholesterol	yes	no
polio	yes	no
diptheria	yes	no

Have you ever experienced any of the following? Please circle appropriate response:

frequent headaches	yes	no
frequent colds	yes	no
nose bleeds	yes	no
recurrent sore throats	yes	no
wheezing spells	yes	no
coughed up blood	yes	no
coughing up phlegm	yes	no
heart palpitations	yes	no
chest pain w/exercise	yes	no
dizzy spells	yes	no
shortness of breath	yes	no
swollen feet/ankles	yes	no
heartburn or intestinal problems	yes	no
pain or cramps in legs	yes	no
painful joints	yes	no
ulcers	yes	no
recurrent constipation	yes	no
recurrnet diarrhea	yes	no
prostrate trouble	yes	no
kidney problems	yes	no
phlebitis	yes	no
varicose veins	yes	no
osteoporosis	yes	no

<u>Smoking</u> Check the appropriate response below.

never smoked _____ stopped more than 10 years ago _____
smoke up to 1 pack/day _____ smoke 1-2 pack/day._____ 3+
pack/day _____

What type of smoking? (circle all that apply) cigarette cigar
pipe

Alcohol

How many alcoholic beverages per week do you consume? (circle one)
none   up to 2/week   3-7/week   7-10/week   10+/week
What type of alcohol do you drink? ____________________

Exercise

If you participate in a **regular** aerobic exercise program such a jogging or soccer, please indicate the frequency and type of exercise below. **Regular** means 3 or more times/week.

Circle one of the following:
<once/week (circle if yes)   yes
1-3 times/week (circle one)   yes   no
type:______________________
4-5 times/week (circle one)   yes   no
type:______________________
6-7 times/week (circle one)   yes   no
type:______________________

Date of Last Complete Physical Exam: ______________
Normal:_____   Abnormal:_____

Date of Last Eye Exam: ____________
Normal:_____   Abnormal:_____

Date of last Chest X-ray:____________
Normal:_______   Abnormal:______

Date of Last Electrocardiogram: _________
Normal: _____   Abnormal: _____

Date of Most Recent Blood Lipid Analysis:_________
Report values below if known:

Total Blood Cholesterol______ Triglycerides_______
HDL Cholesterol______ LDL Cholesteerol______

Most Recent Hospitalization and Reason: ________________
____

Date and Amount of Last Blood Donation:____________________
____

For Women Only (Circle appropriate responses)

Are you currently pregnant? yes no
Are you currently menstruating? yes no
If yes, are your menstrual cycles regular (once per month)?
yes no

Health Insurance
I do have health insurance (circle one) yes no
If yes, my insurance organization
is:_______________________________

I do have dental coverage (circle one) yes no

Do Not Write Below This line::
Total Number of Cardiovascular Risk Factors:________

UNIVERSITY OF MARYLAND
INSTITUTIONAL REVIEW BOARD

2100 Lee Building
College Park, Maryland 20742-5121
301.405.4212 TEL 301.405.8386 FAX

Reference: *IRB HSR Identification Number – 01agric001*

March 2, 2001

MEMORANDUM

Notice of Results of Final Review by IRB on HSR Application

TO:
Dr. Arthur T. Johnson
Ms. Karen M. Coyne
Department of Biological Resources Engineering

FROM:
Dr. Marc A. Rogers, Co-Chair
Dr. Joan A. Lieber, Co-Chair
Institutional Review Board

RE:
Project entitled "The Effects of Resistance on the Relationship Between Tidal Volume, Minute Volume, and Oxygen Consumption During Steady-State Exercise"

The Institutional Review Board (IRB) concurs with the departmental human subjects review board's preliminary review of the above referenced human subjects application. This application has IRB approval for this human subjects research and has been placed on file in the IRB office. If there are any deviations from the approved protocol, you are required to submit the modifications to your departmental human subjects review committee.

If there are any questions about this, please contact either of us at mr68@umail.umd.edu or jl39@umail.umd.edu or at extension 54212. Thanks very much.

/rcf
enclosures

Consent Form

Title: The effects of resistance on the relationship between tidal volume, minute volume, and oxygen consumption during steady state exercise

I, ____, state that I am between the ages of 18 and 39 years old and wish to participate in a project being conducted by Arthur Johnson, Ph.D., Karen Coyne, and William Scott of the University of Maryland's Biological Resources Engineering Department on the College Park campus. The purpose of this study is to assess the effects of breathing resistance on the relationship between the volume of air exhaled with each breath, the volume of air respired during one minute, and oxygen consumption. The data to be obtained from this study will help to quantify the relationships.

I understand that, prior to participation in this study, I will report to the laboratory for an orientation session that will last approximately 30 minutes. At this session, this informed consent, which describes the procedures, methods, and individual subject rights for this study, will be given to me for my review. I understand that I will be asked to complete a medical history questionnaire that details my medical history. I understand that I will be asked to complete a PAR-Q questionnaire that will assess my ability to participate in physical activity. I understand that I will also be asked to complete a computer-administered survey that will be used to rate my general level of anxiety. I understand that this survey is not a reflection of my past or present emotional stability. I understand that an investigator will be present to answer any questions that I may have concerning this investigation and my participation.

I have been informed that on my first visit for testing I will undergo a maximal exercise test. This test will be done on a treadmill and involves exercise that allows work rate to be increased progressively until I become exhausted and decide to end the test or other signs or symptoms dictate the stoppage of this test. I understand that I will probably become exhausted within 9 – 15 minutes during this maximal exercise test. Also, I am aware that this entire session will require about one hour of my time. I understand that my blood pressure, heart rate, rating of perceived exertion, and oxygen consumption will be monitored throughout the maximal exercise test. I understand that performance of any exercise test involves some risk to my heart and lungs, which are potentially life threatening. However, I understand that this risk is minimal for individuals within my age group who have no known symptoms of heart or lung disease. The risk of death during or immediately after an exercise test is less than or equal to 0.01%. The results of my maximal exercise test will be used to assess by cardiorespiratory fitness for study participation and to determine the exercise level that I will be exposed to for subsequent treadmill tests.

I understand that I will be asked to complete three conditions of submaximal treadmill exercise and that these conditions will be randomly assigned and will occur on different test days. These test sessions will involve constant load exercise at intensities of 25-30%, 35-40%, 45-50%, 65-70%, and 80-85% of my maximal exercise capacity while wearing either a full-facepiece mask with varied inspiratory and expiratory breathing resistances. I understand that it may be uncomfortable to breathe when wearing the mask especially when I am exposed to a high level of breathing resistance. I understand that I will exercise at each intensity level until my oxygen consumption has reached a steady-state. I am aware that it may take 3 to 6 minutes to reach a steady-state at each intensity level and that I will be walking on the treadmill for 15 to 30 minutes. I understand that a test administrator will stop a test for medical reasons (e.g., abnormal ECG, heart rate, etc.) or if there is an unforeseen problem with data collection equipment. These three treatment sessions will occur after my initial maximal exercise test session. I understand that each treatment session will require about one hour of my time.

I understand that the following measures will be obtained at various times throughout each test session: heart rate, oxygen consumption, minute volume (the volume of air respired during one minute), tidal volume (the volume of air exhaled with each breath), breathing resistance, rating of perceived exertion, breathing apparatus comfort, and thermal sensation. I understand that my blood pressure may also be taken at various times throughout each test session. I will also be asked to complete the computer-administered State-Anxiety survey, a measure of situational anxiety, before and after each exercise session. I also realize that I will complete a test to assess the level of respiratory resistance that exists within my lungs and air passages. I have been instructed that this test will require me to use a mouthpiece and a nose-clip and to breathe normally in and out of my mouth while I hold my cheeks with my hands. I understand that several breaths will be analyzed to record my respiratory resistance but that the test is normally completed within 5 minutes. I understand that all testing procedures will be conducted at ambient room temperature (74°F) in an environmentally controlled laboratory. I have been advised to get adequate rest the night before each test, to eat breakfast or lunch, and to drink plenty of fluids, excluding alcohol and caffeine, before reporting to the laboratory. I understand that I need to bring my own T-shirt, shorts, socks, and sneakers to wear for all trials.

I am aware that I am free to ask questions about this study and withdraw my participation at any time without any penalty. I realize that the University of Maryland does not provide any medical or hospitalization insurance coverage for study participants nor will the University provide compensation for any injury sustained as a direct result of participation in this study except as required by law. I understand that I will be asked about my health status before each test session to insure that I have no condition that would jeopardize my safety or health. I am aware that if I am excessively tired, have any musculoskeletal injury, have recently consumed excessive amounts of alcohol, or report to have a cold I will not be allowed to participate in testing. I understand that if this situation should arise that I will be rescheduled for testing at another time once I have fully recovered from my ailment. I understand that accidents may result in bodily injury during physical activity. However, I am aware that the risk of this is far less during the completely supervised activities used in a research study than in unsupervised exercise or competitive sports. I have been informed that some individuals have experienced minor skin irritations as a result of the procedures used to obtain heart rates. I understand that this condition is commonly resolved within a short period of time.

I understand that any information gathered in this study that pertains to me will be held in the strictest confidence and will not be revealed to anyone that is not directly involved with this investigation. I understand that this study has not been designed for my benefit. I understand that I will not receive any monetary benefits for my participation. However, I will be given information regarding my general fitness level. I understand that I am free to withdraw as a participant without being penalized in any way. I am aware that I may request to withdraw either by word of mouth or in writing. I understand that I must sign this informed consent before I will be allowed to participate in this investigation. I am aware that I will be given a copy of the signed consent form prior to beginning my participation.

Investigators:

Karen Coyne, Arthur Johnson, Ph.D., and William Scott
Department of Biological Resources Engineering
University of Maryland
College Park, MD 20742

Karen Coyne's phone: (301) 405-1186 or (410) 675-4578
Arthur Johnson's phone: (301) 405-1184
William Scott's phone: (301) 405-1199

IRB APPROVED
VALID UNTIL
FEB 28 2002
UNIVERSITY OF MARYLAND
COLLEGE PARK

Volunteer's signature Date

Witness's signature Date

May 15, 2001

MEMORANDUM

To: Dr. Marc A. Rogers, Chair
Human Subjects Review Committee
Department of Kinesiology

From: Karen M. Coyne

Re: Project entitled "The Effects of Resistance on the Relationship Between Tidal Volume, Minute Volume, and Oxygen Consumption During Steady-State Exercise" originally approved February 19, 2001

The treadmill in our lab does not go slow enough to allow three of my subjects to work in the 25-30% of maximal oxygen consumption range necessary for the project. I would like to amend the above protocol to have these three subjects step up and down a 22.5 cm step at a rate that would put them in the targeted range.

Thank you.

Advisor's Signature: Arthur T Johnson

Appendix B Additional Figures

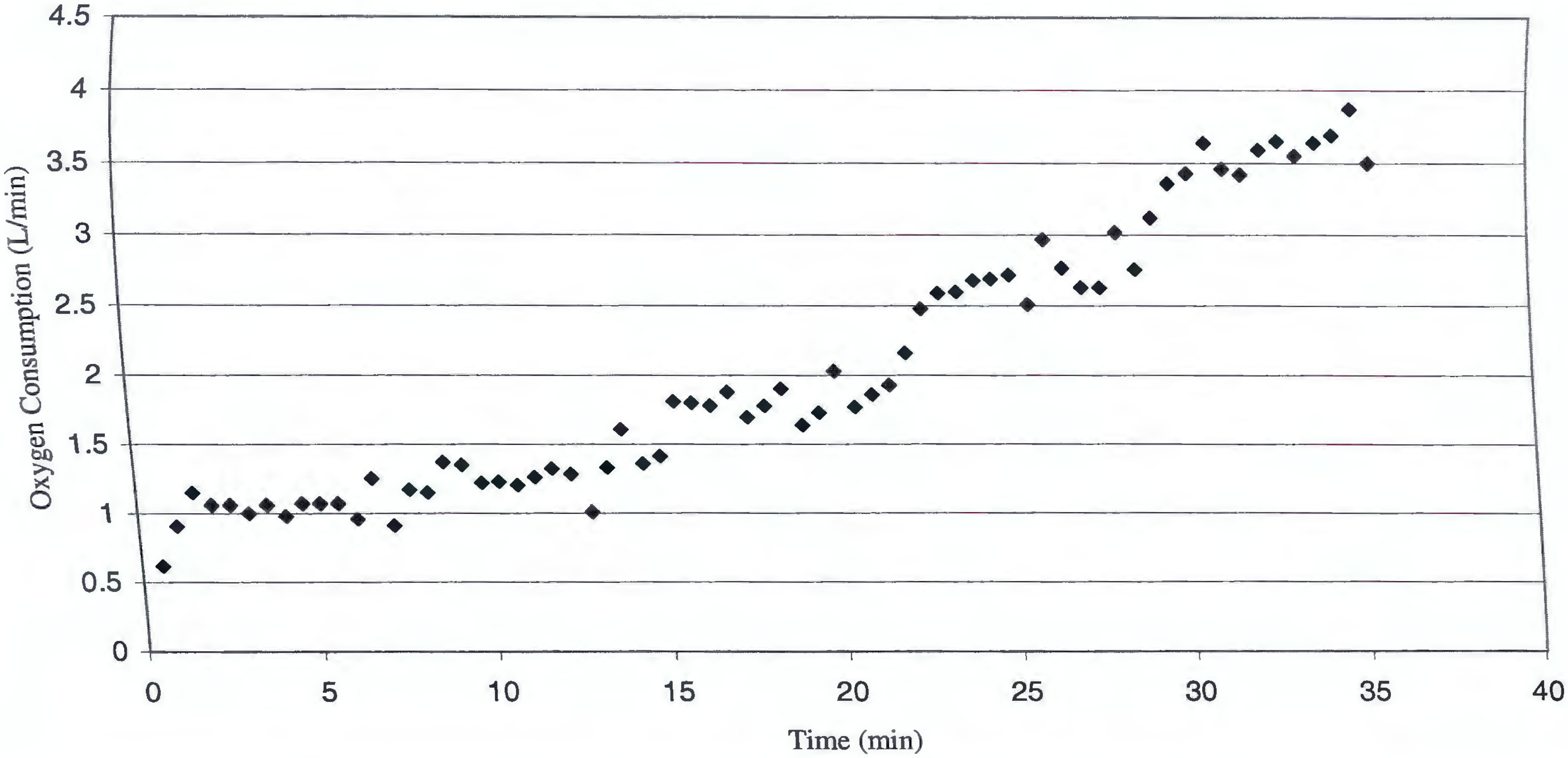


Figure 64. First test of respirator condition A for subject 145. The five stages of the test were run consecutively without a break.

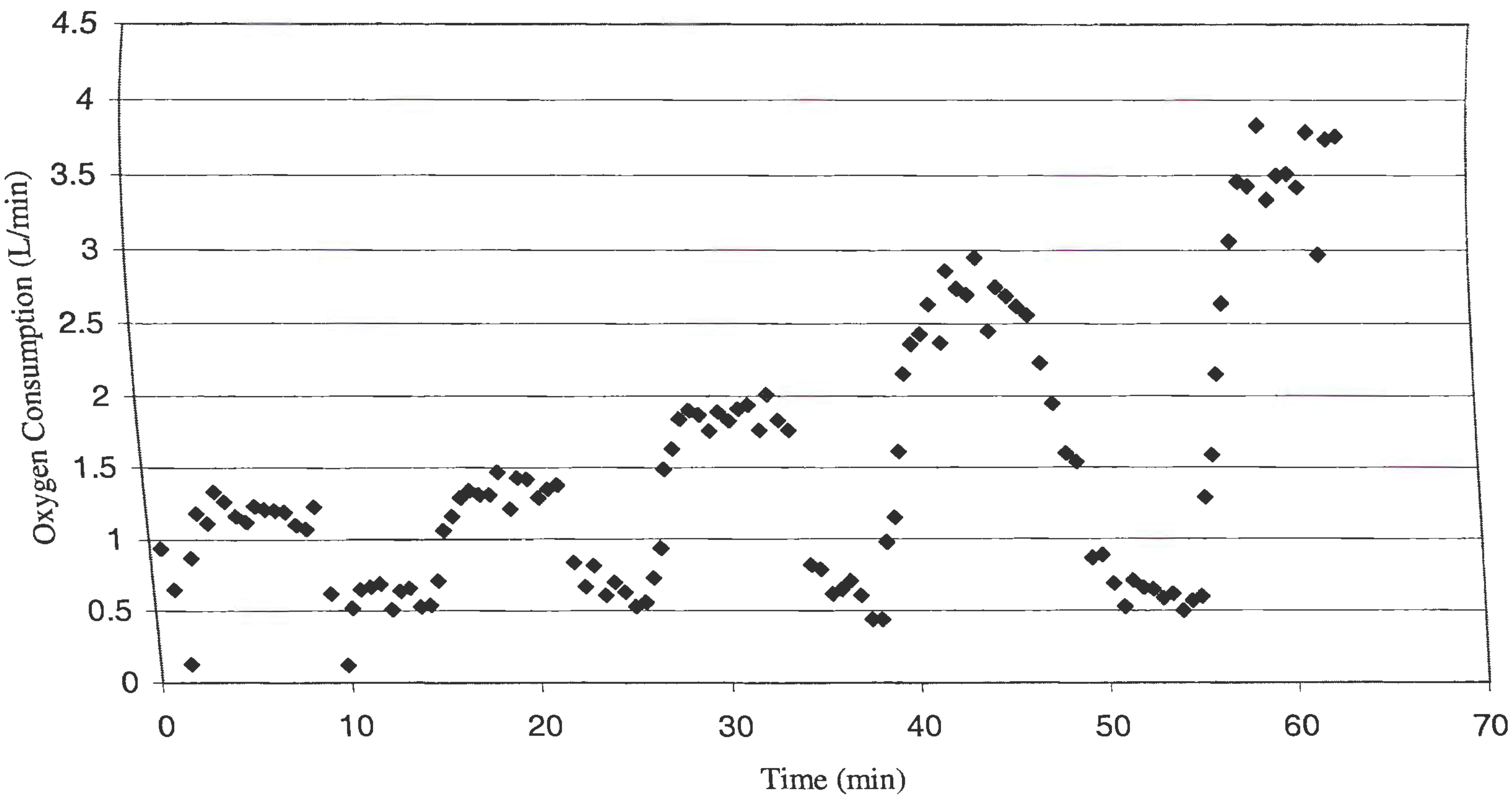


Figure 65. Second test of respirator condition A for subject 145. After each stage, the subject rested until oxygen consumption returned to baseline.

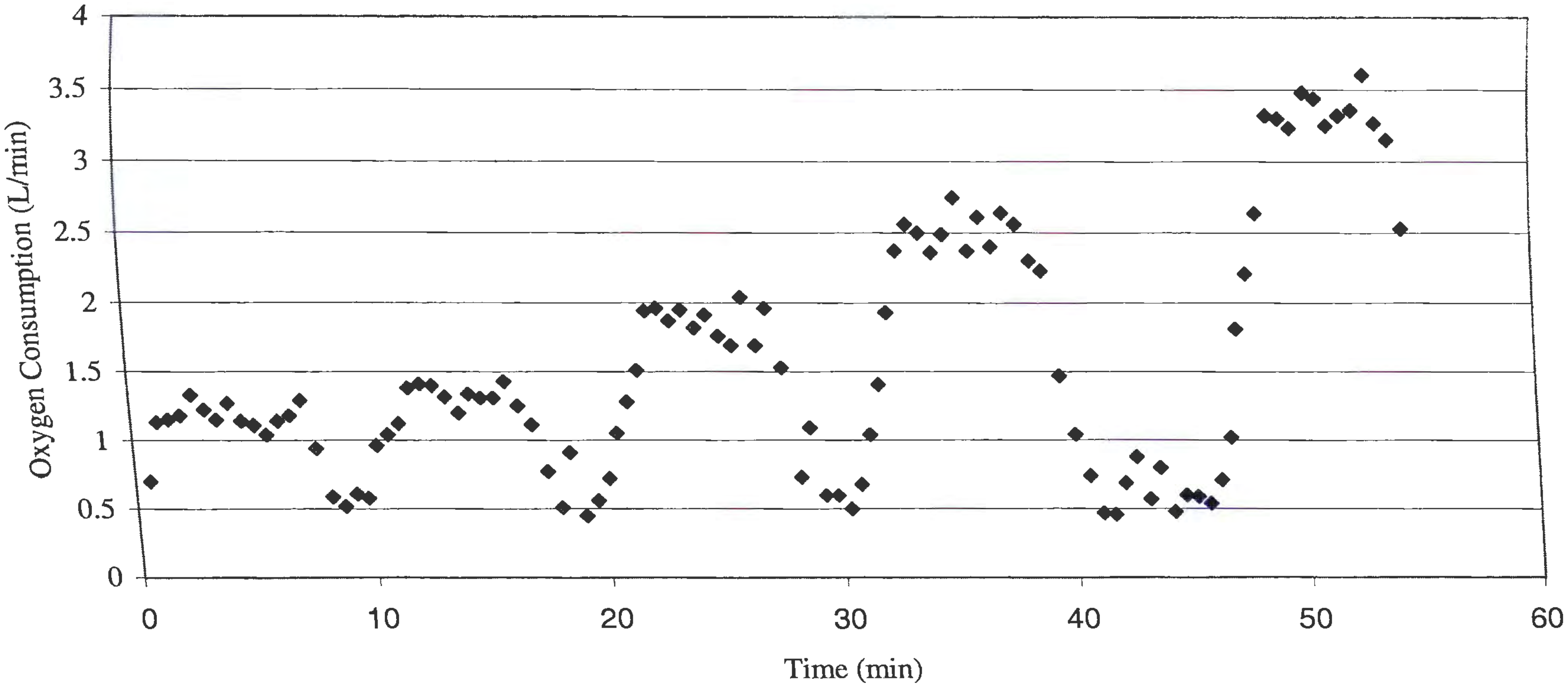


Figure 66. Third test of respirator condition A for subject 145. After each stage, the subject rested until oxygen consumption returned to baseline.

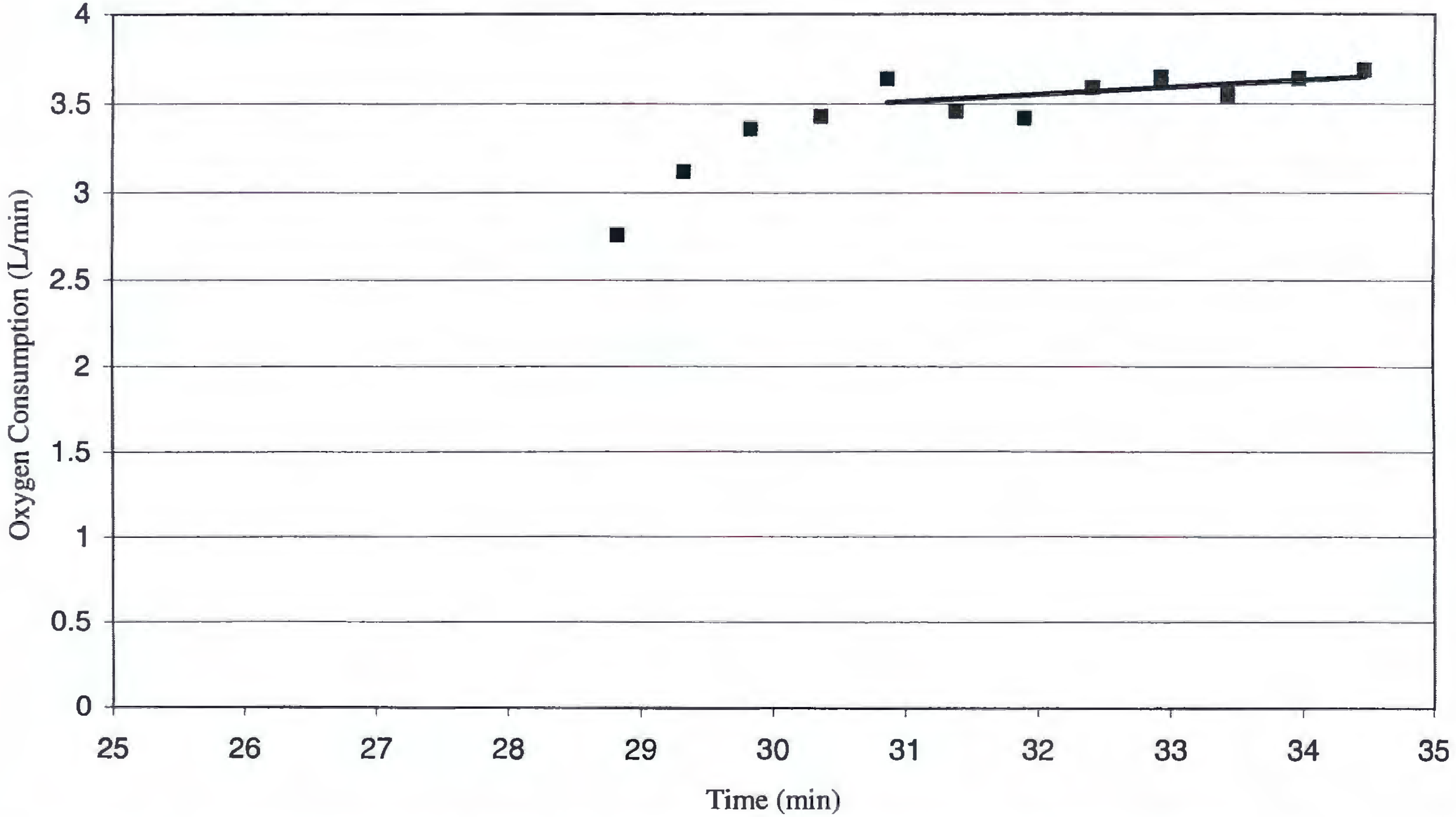


Figure 67. Regression equation fit to last four minutes of data for stage 5 of the first test of respirator condition A for subject 145.

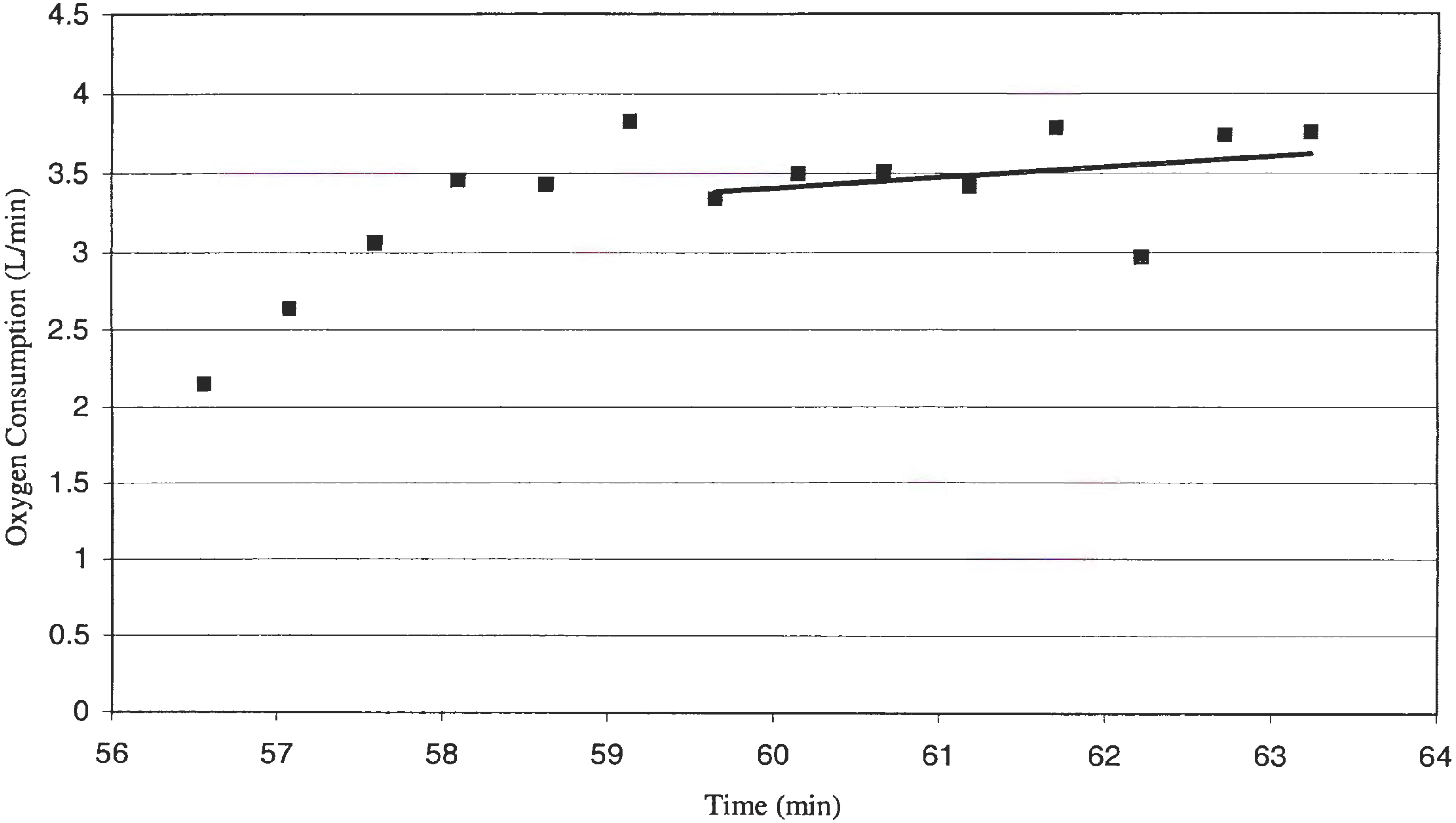


Figure 68. Regression equation fit to last four minutes of data for stage 5 of the second test of respirator condition A for subject 145.

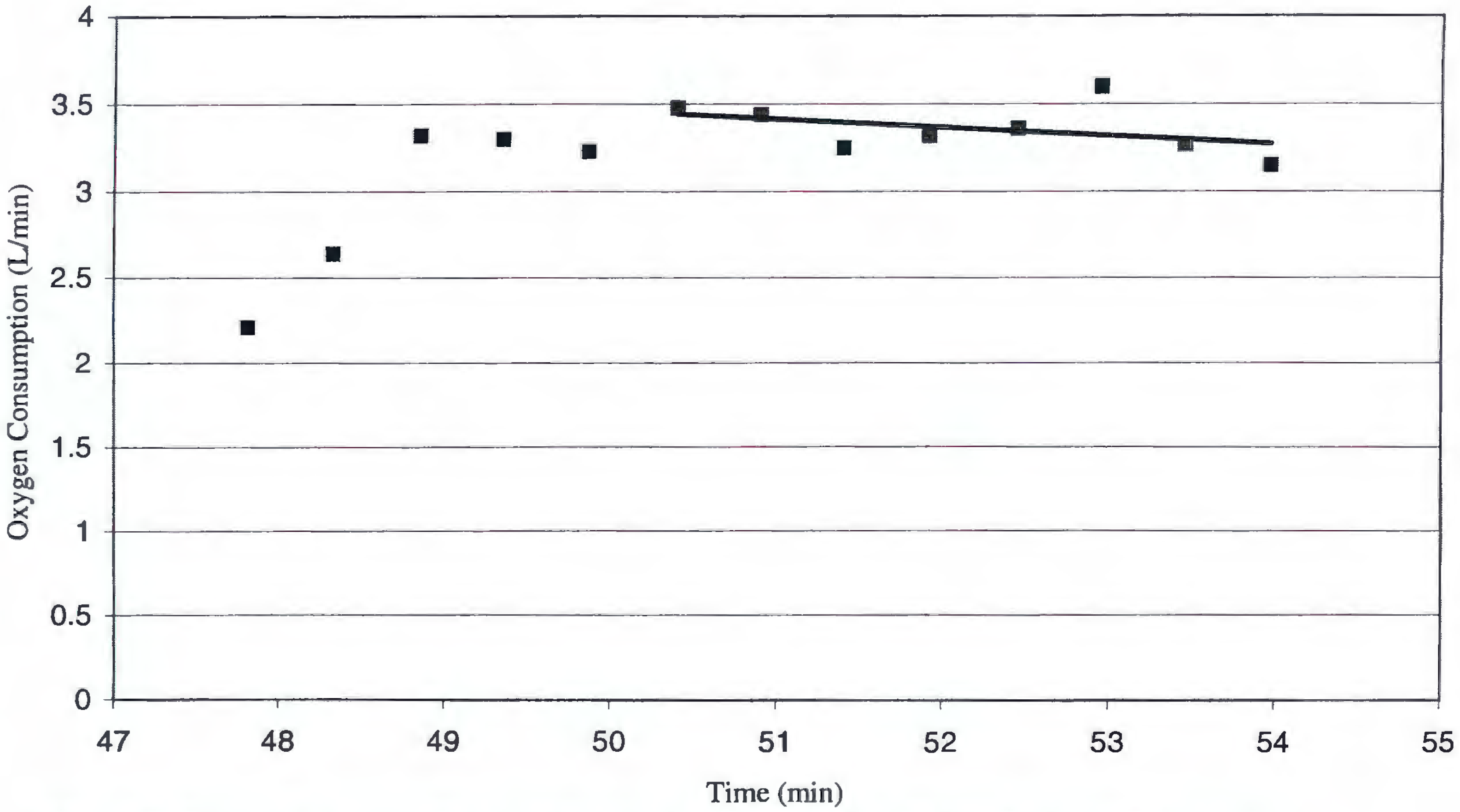


Figure 69. Regression equation fit to last four minutes of data for stage 5 of the third test of respirator condition A for subject 145.

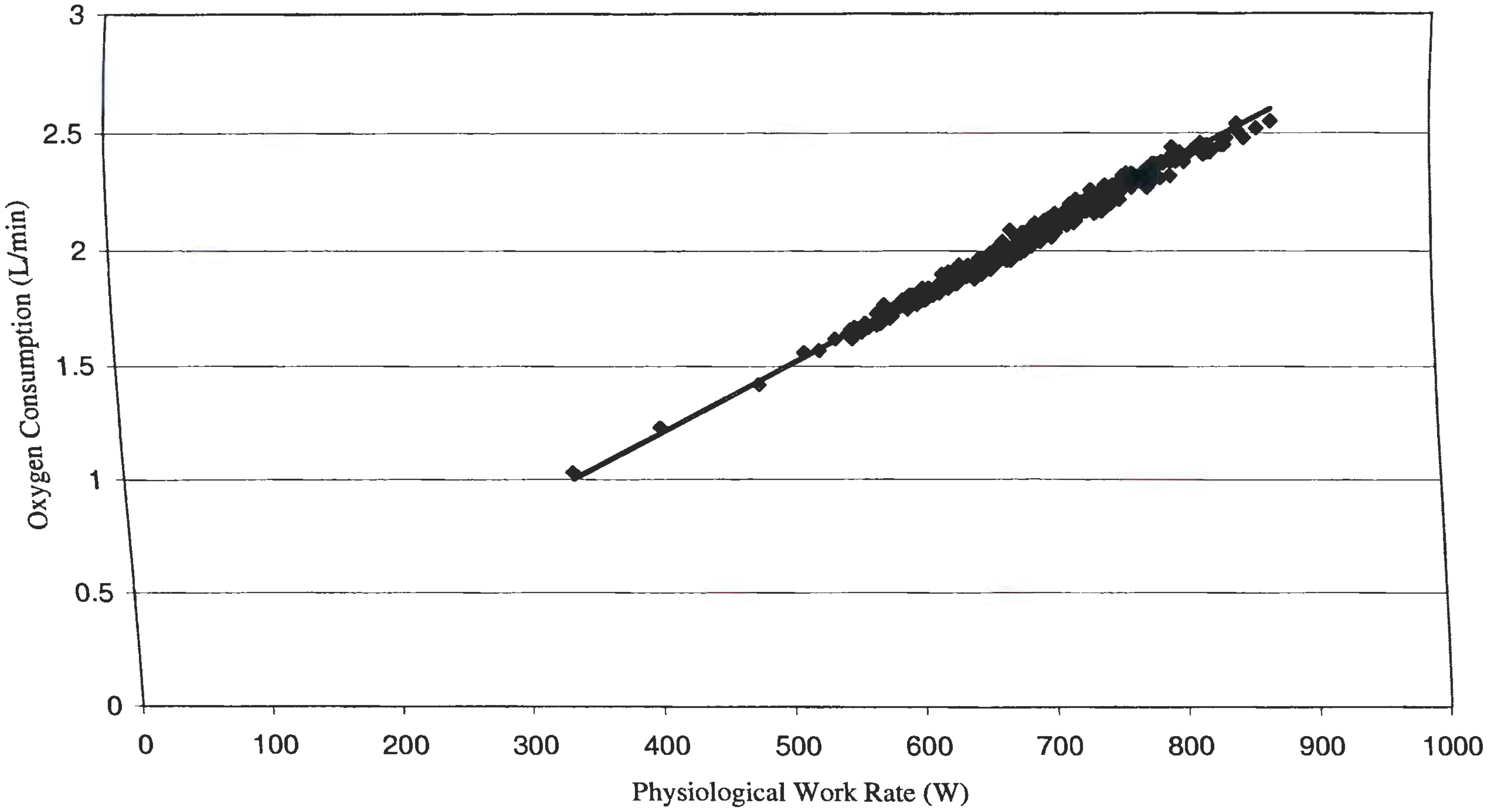


Figure 70. Calibration data and the regression line.

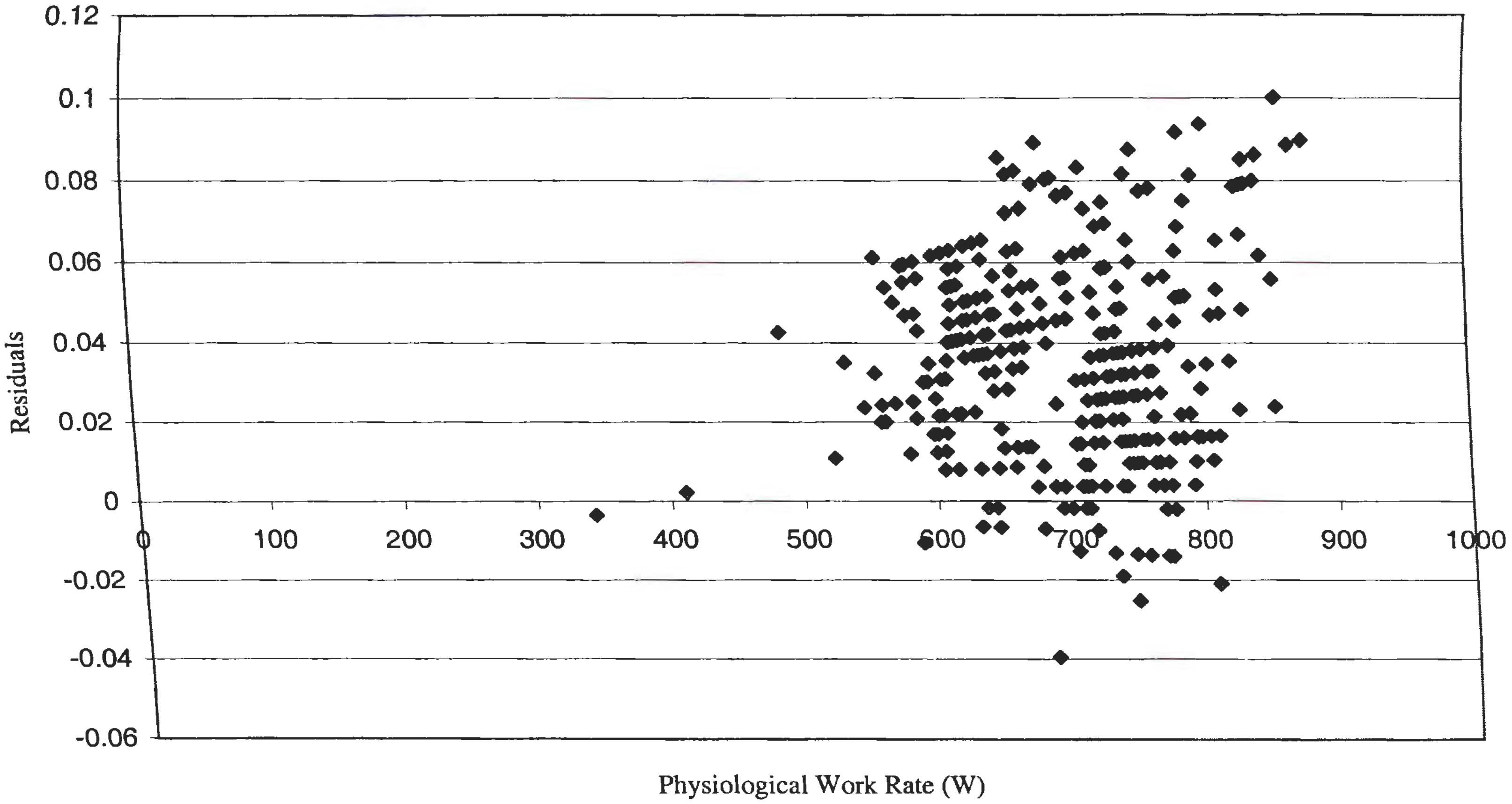


Figure 71. Residuals for the zero-intercept model relating oxygen consumption to physiological work rate.

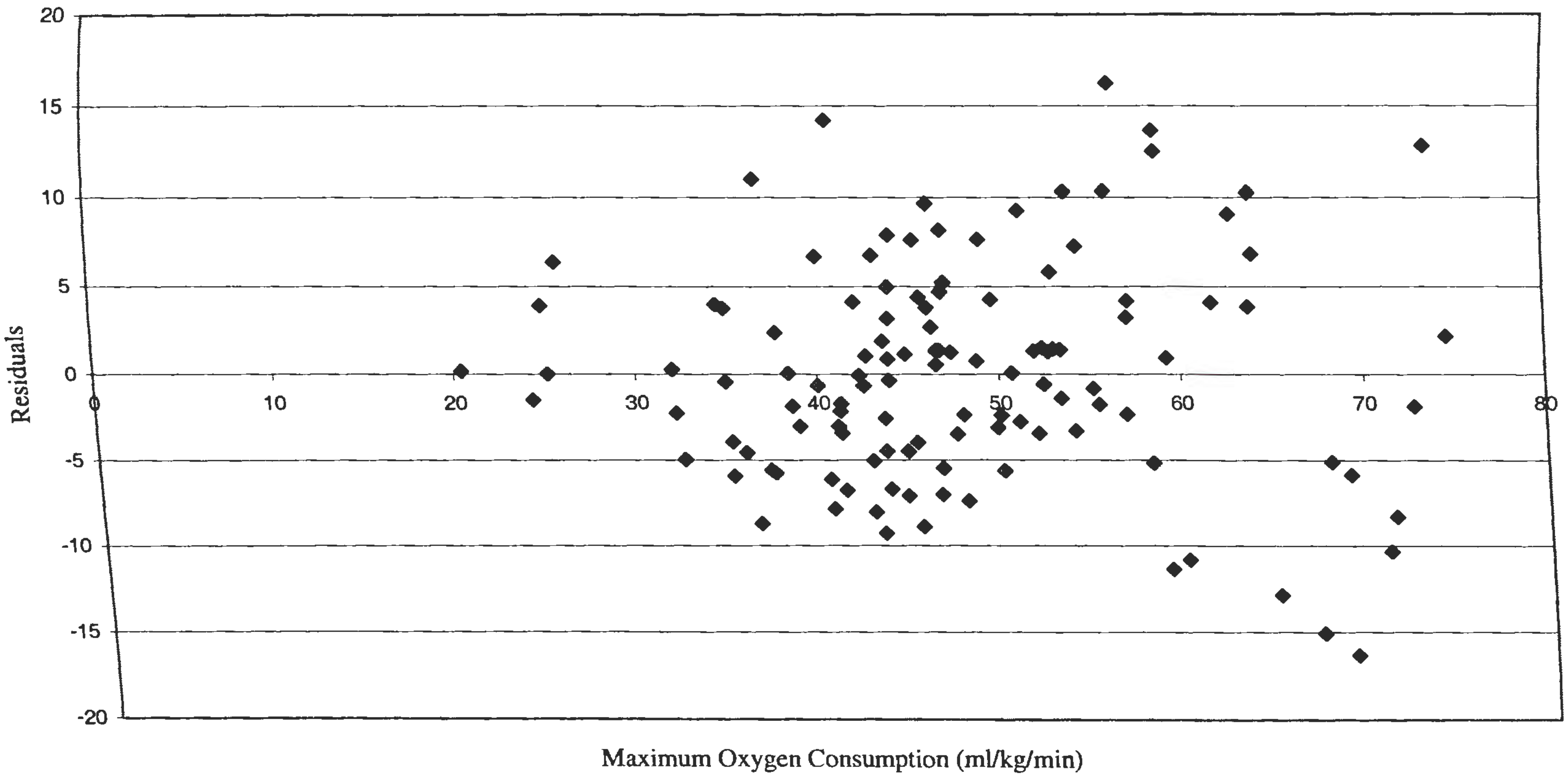


Figure 72. Residuals for linear regression of anaerobic threshold (mL) against maximal oxygen consumption.

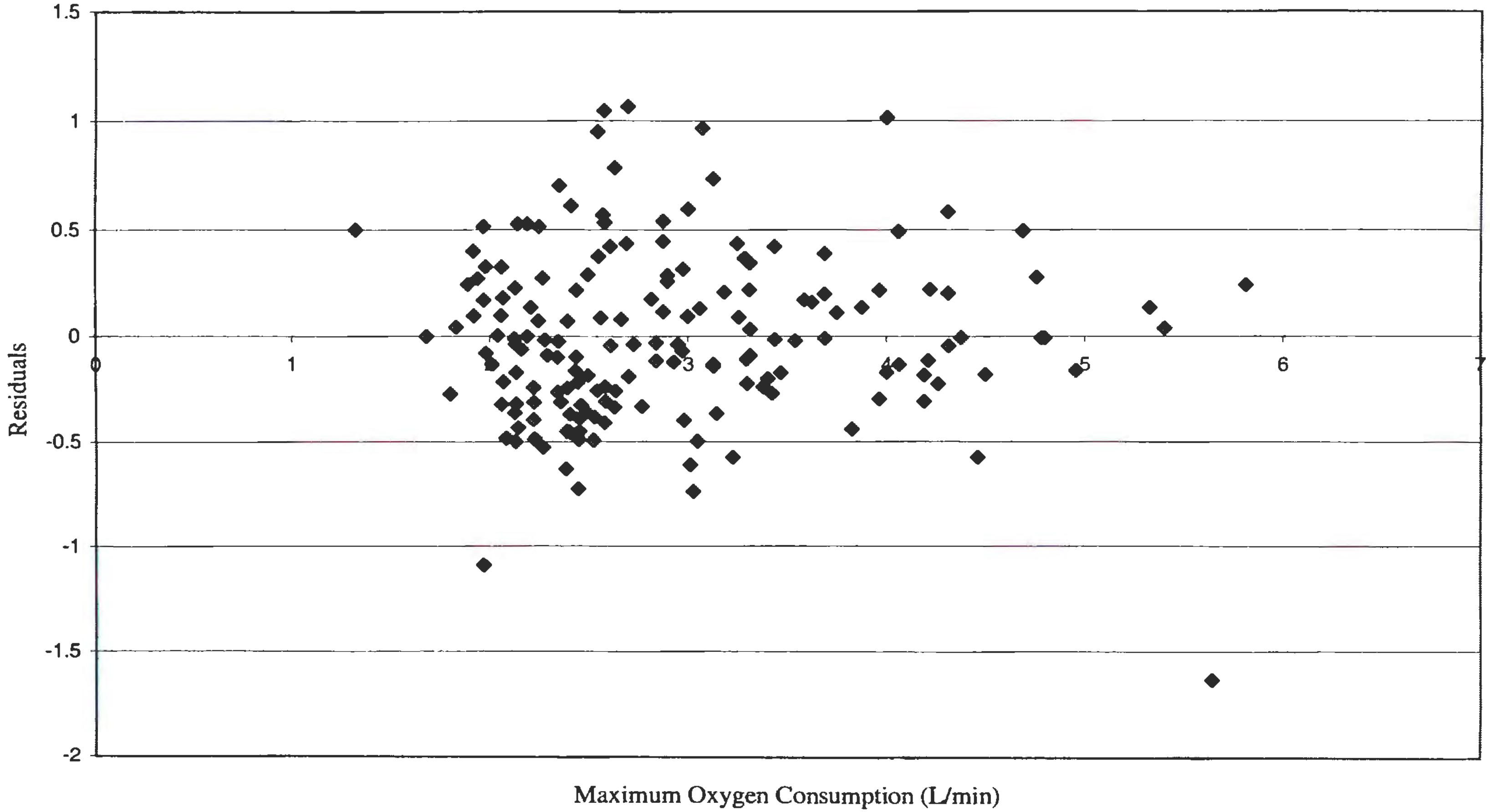


Figure 73. Residuals for linear regression of anaerobic threshold (L) against maximal oxygen consumption.

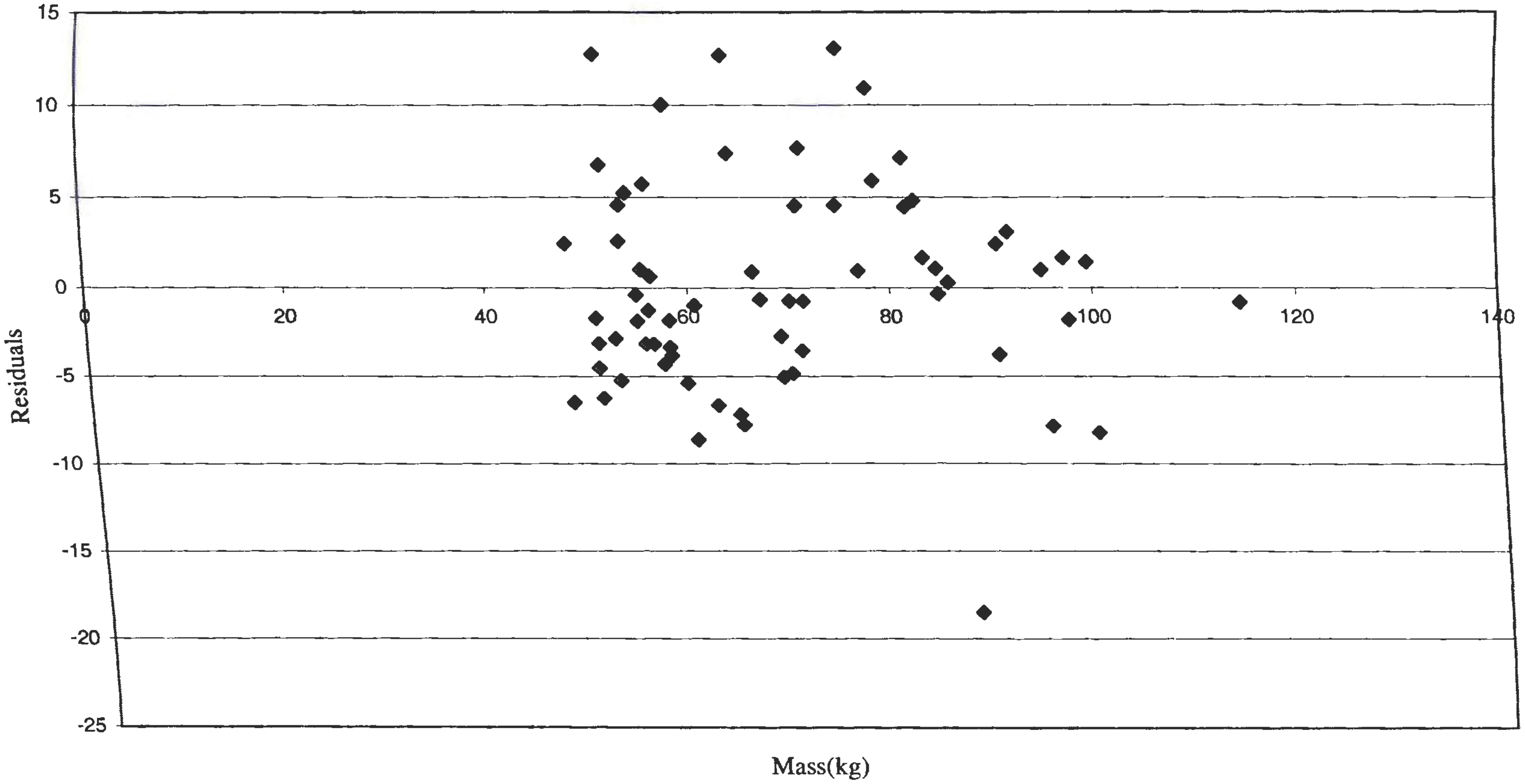


Figure 74. Residuals for multiple regression of anaerobic threshold (mL) versus mass.

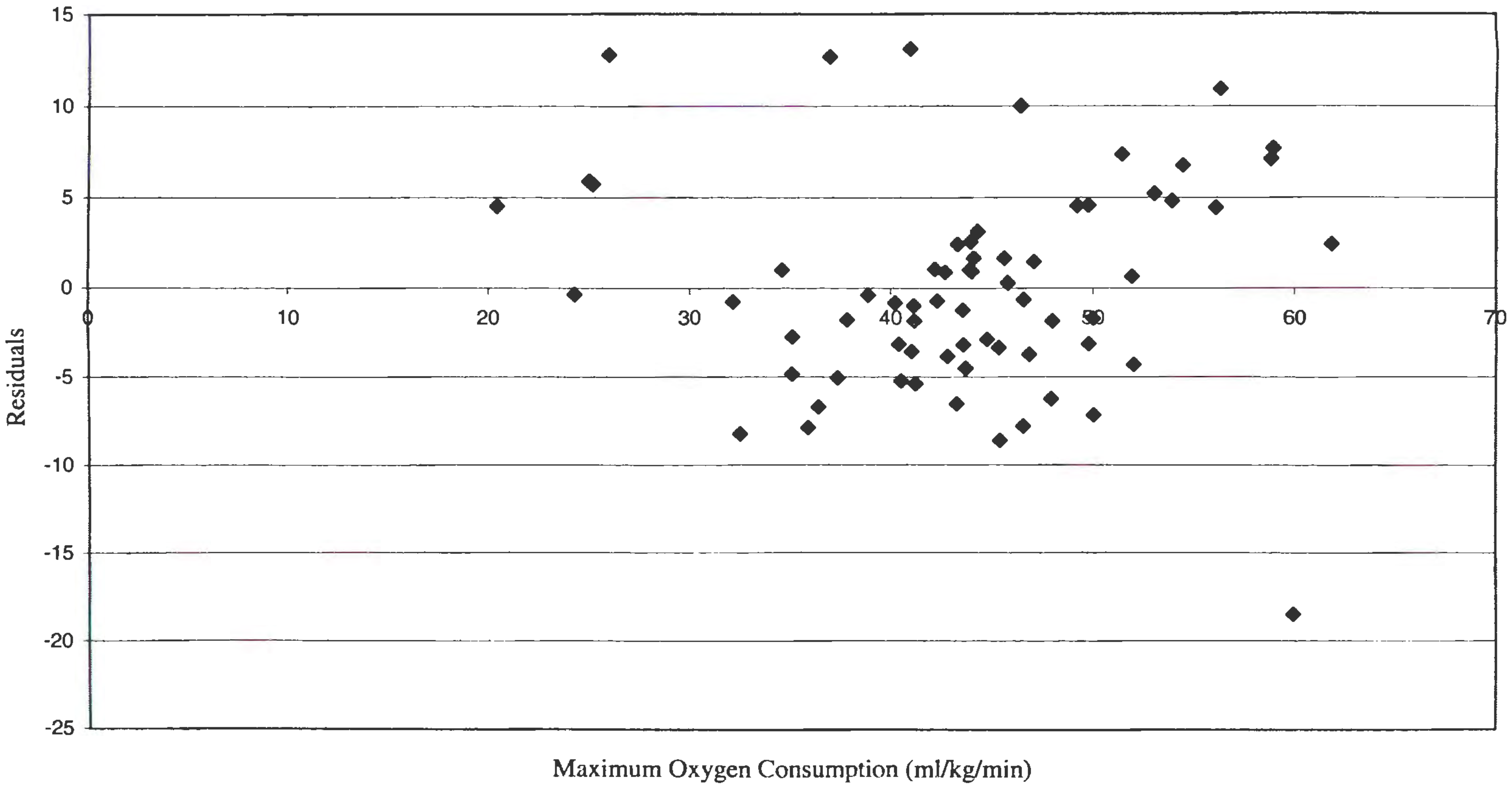


Figure 75. Residuals for multiple regression of anaerobic threshold (mL) versus maximal oxygen consumption.

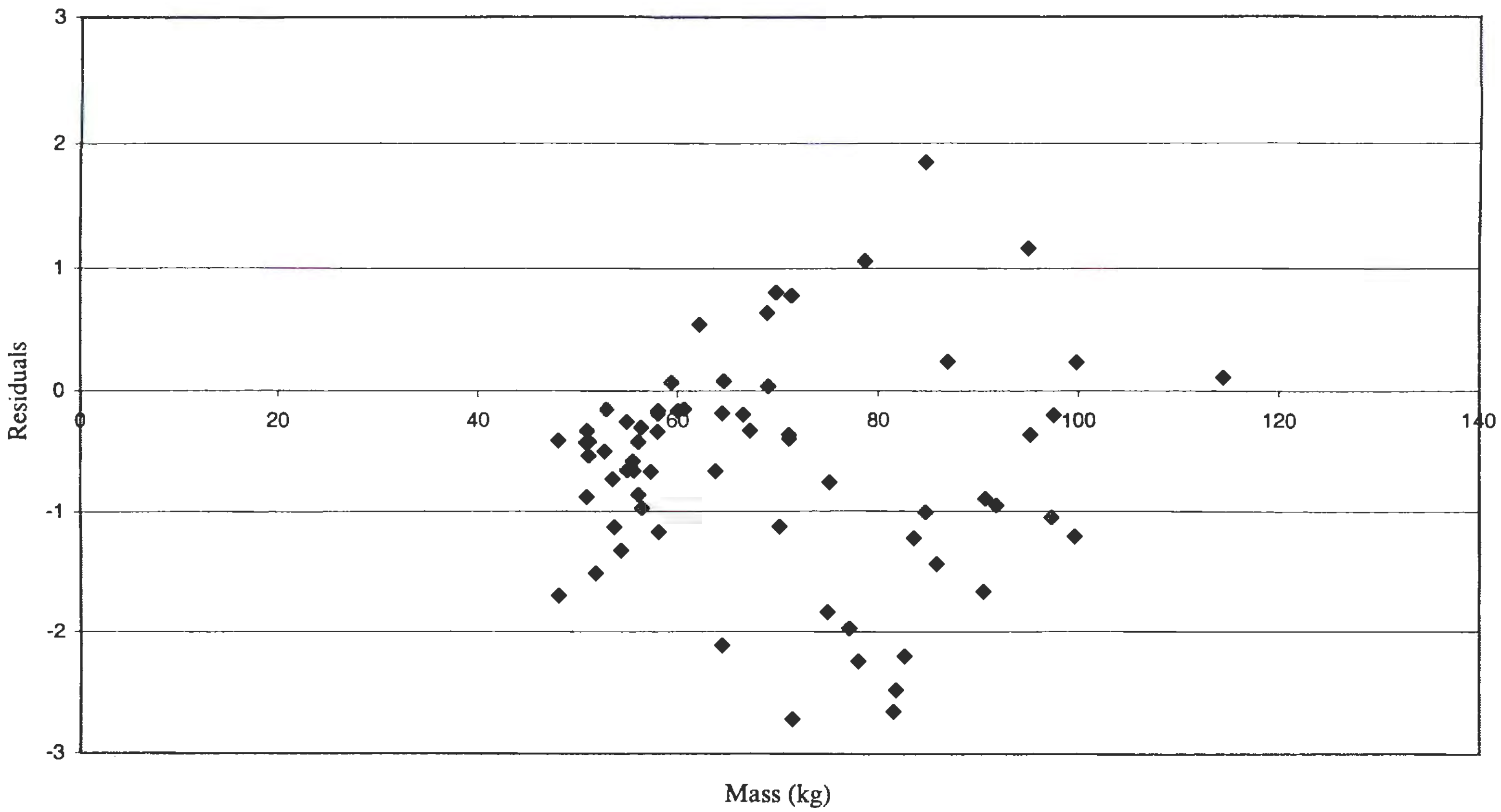


Figure 76. Residuals for multiple regression of anaerobic threshold (L) versus mass.

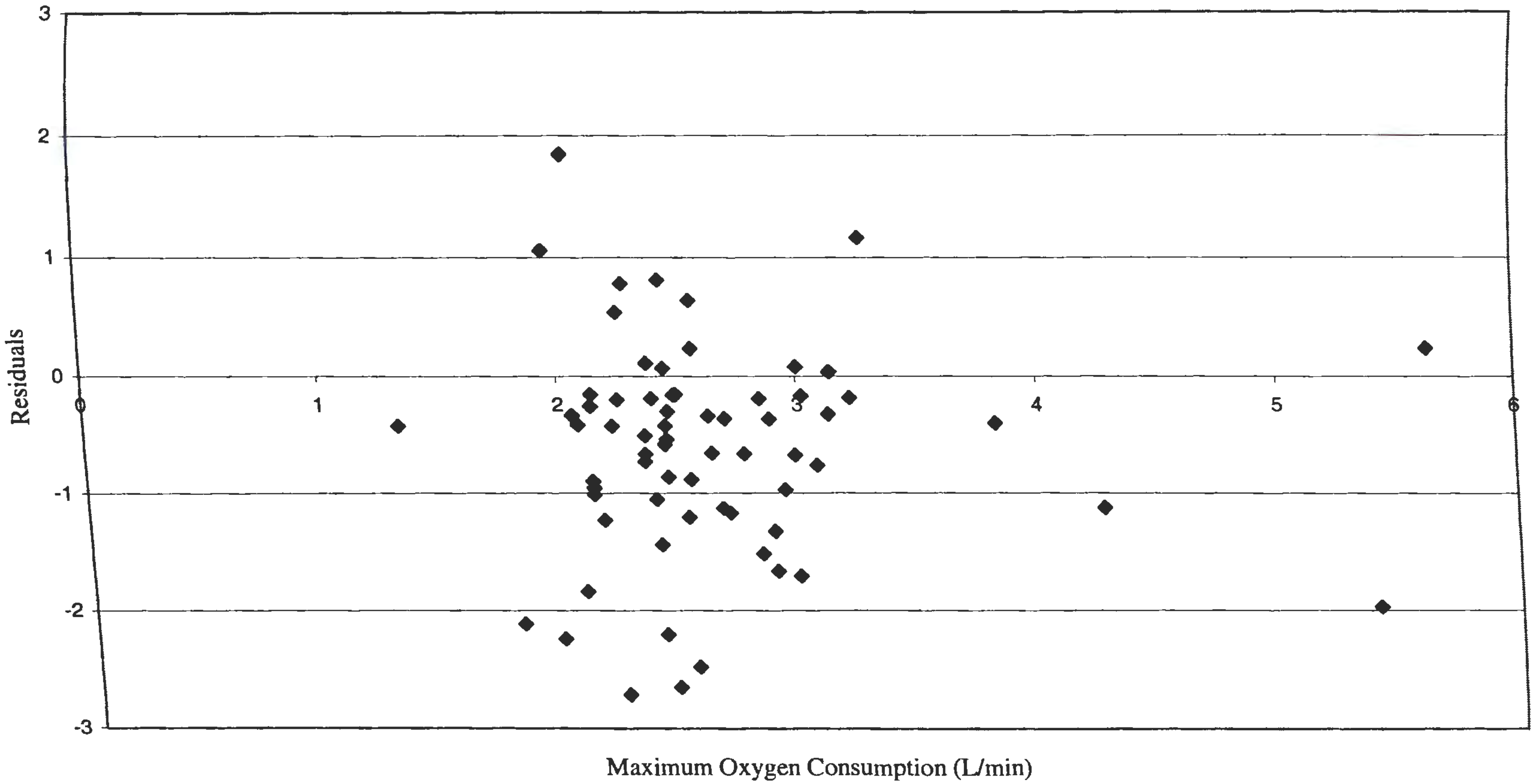


Figure 77. Residuals for multiple regression of anaerobic threshold (mL) versus maximal oxygen consumption.

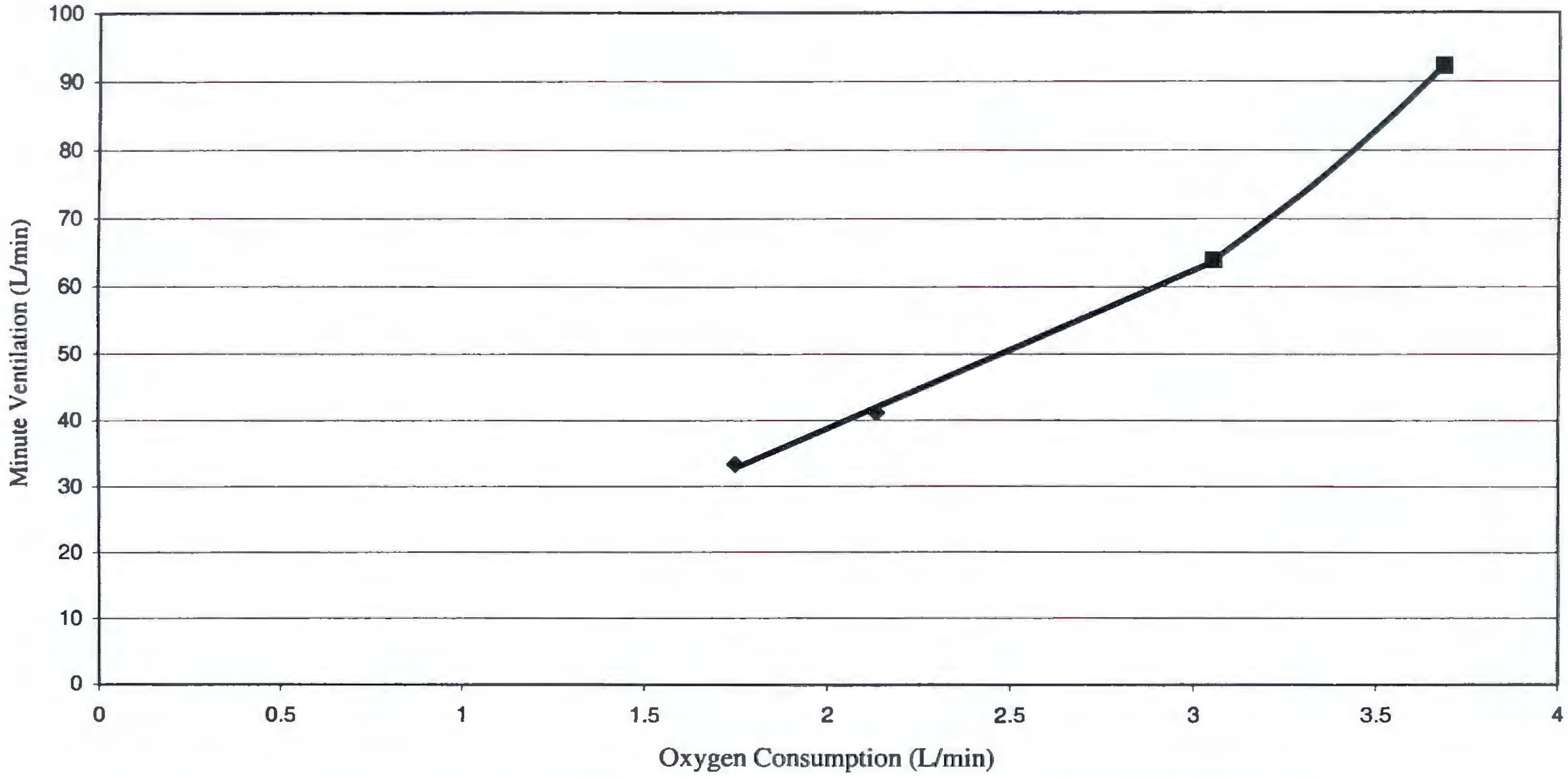


Figure 78. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 001.

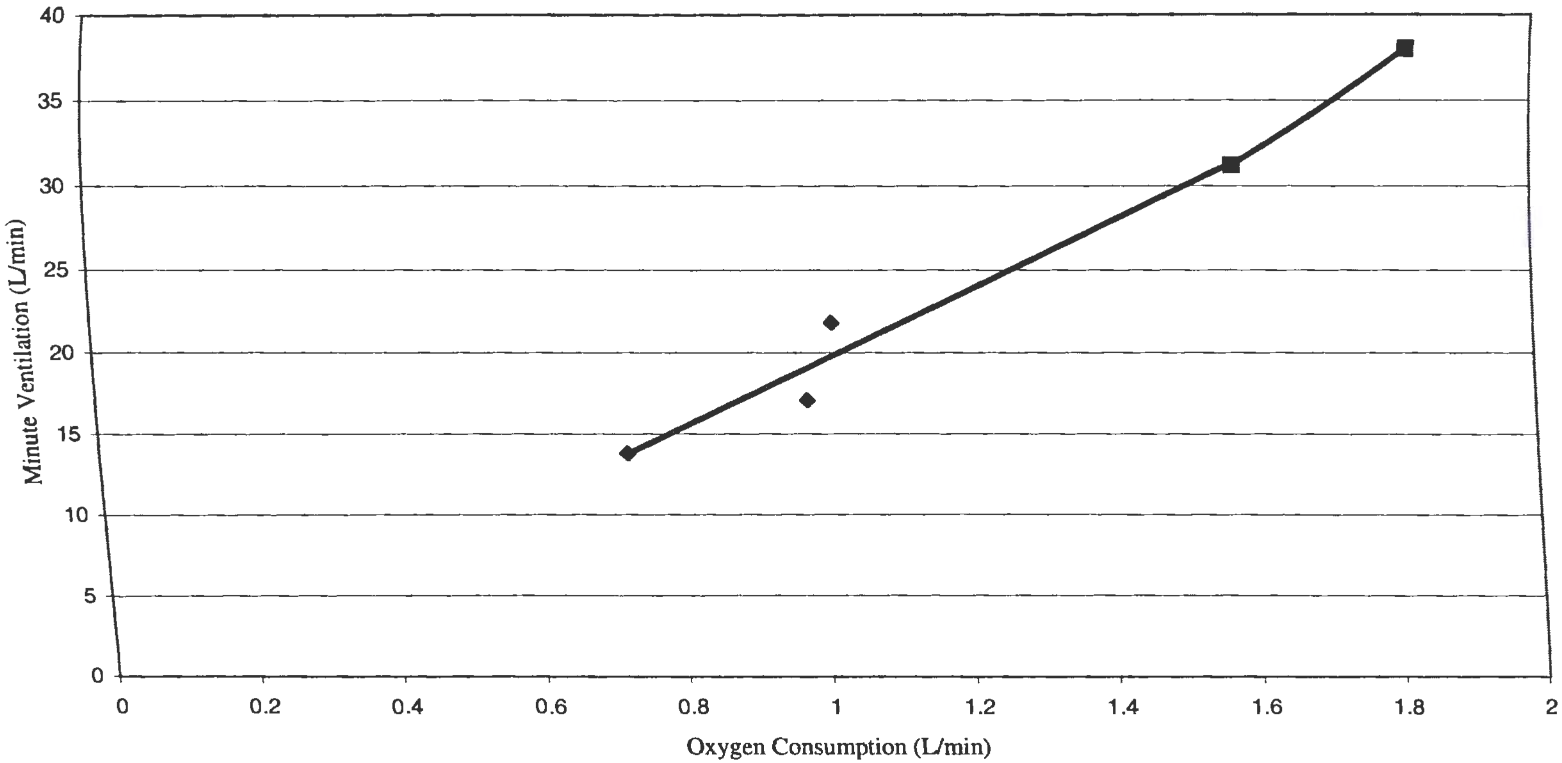


Figure 79. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 002.

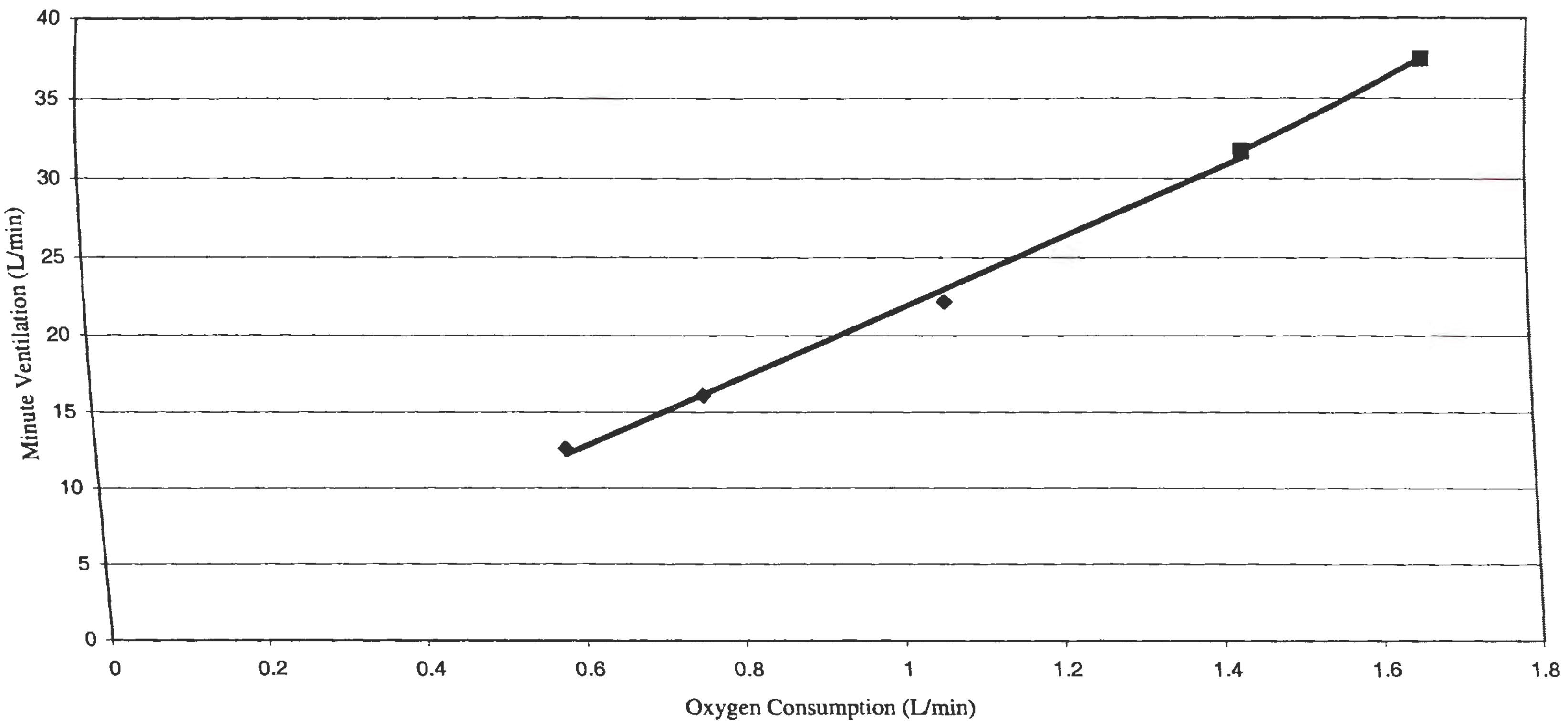


Figure 80. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 023.

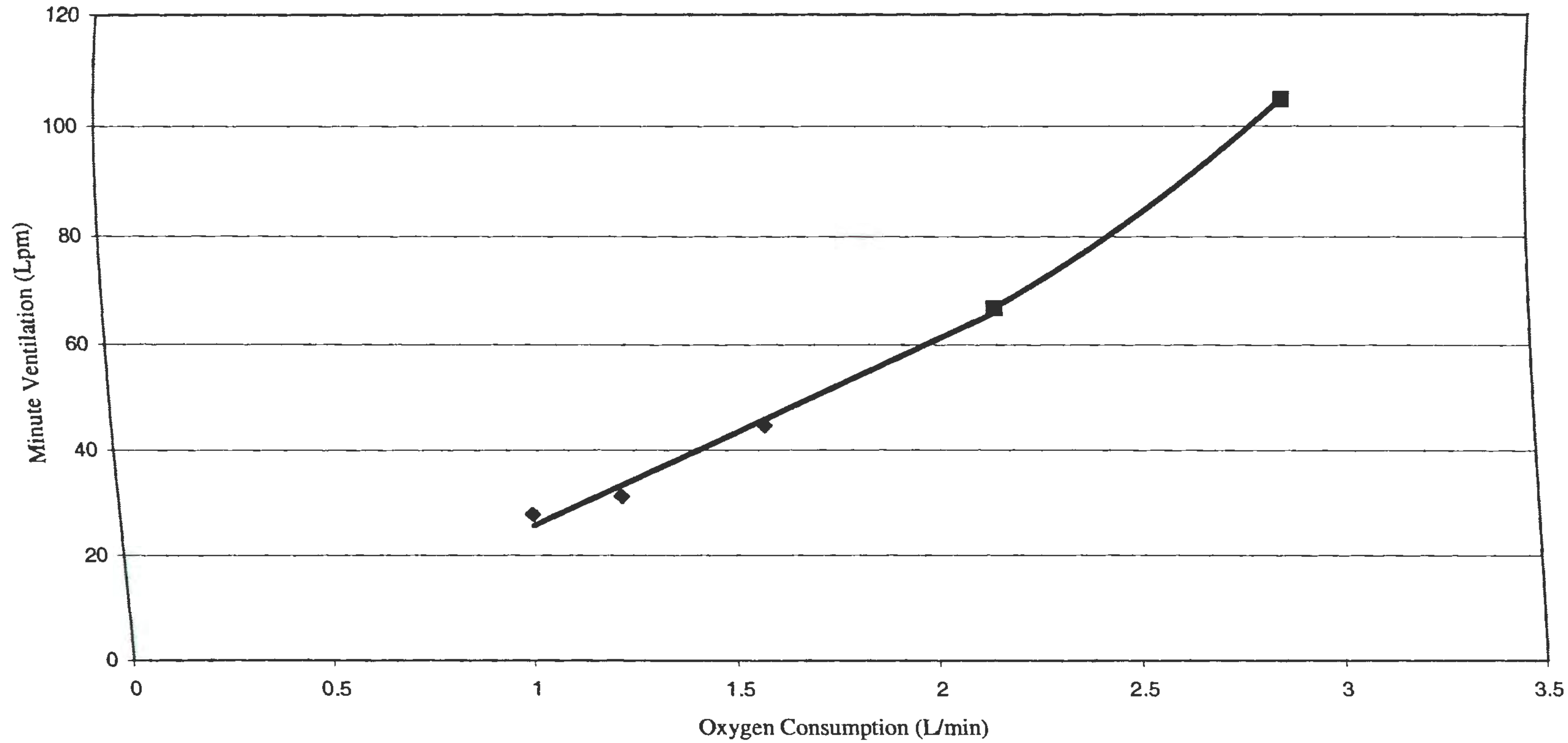


Figure 81. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 145.

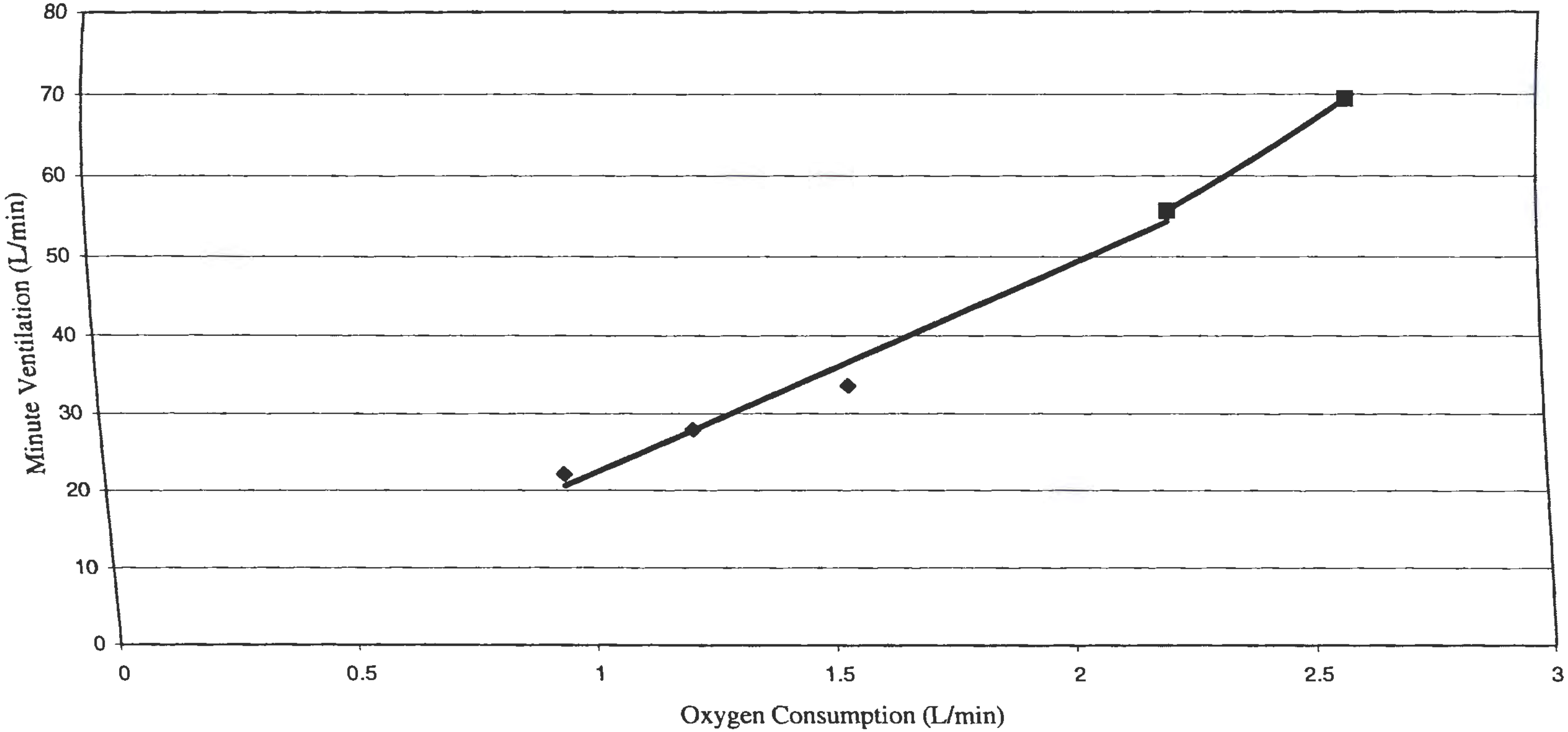


Figure 82. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 173.

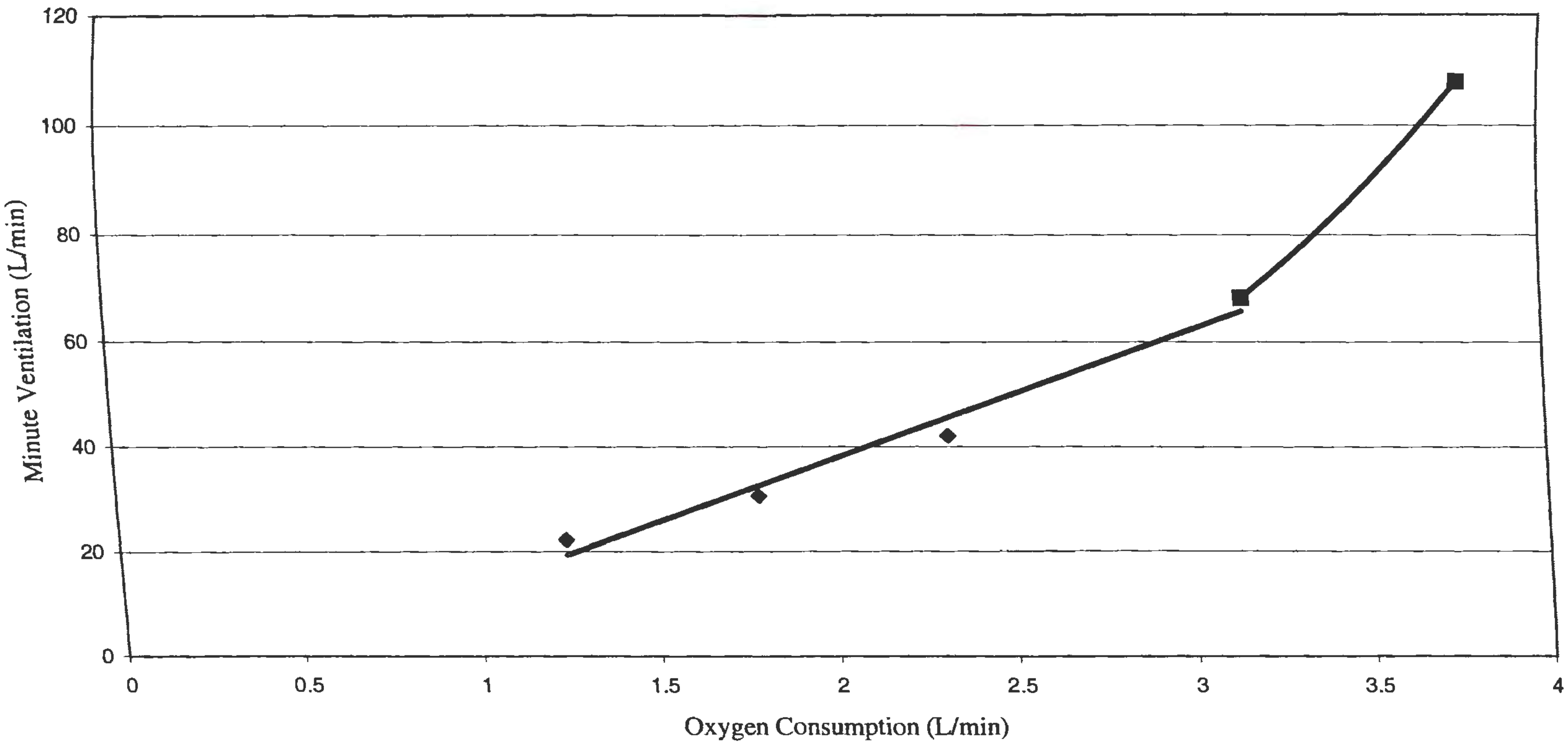


Figure 83. Steady-state minute ventilation versus oxygen consumption obtained during the levels determination session for subject 221.

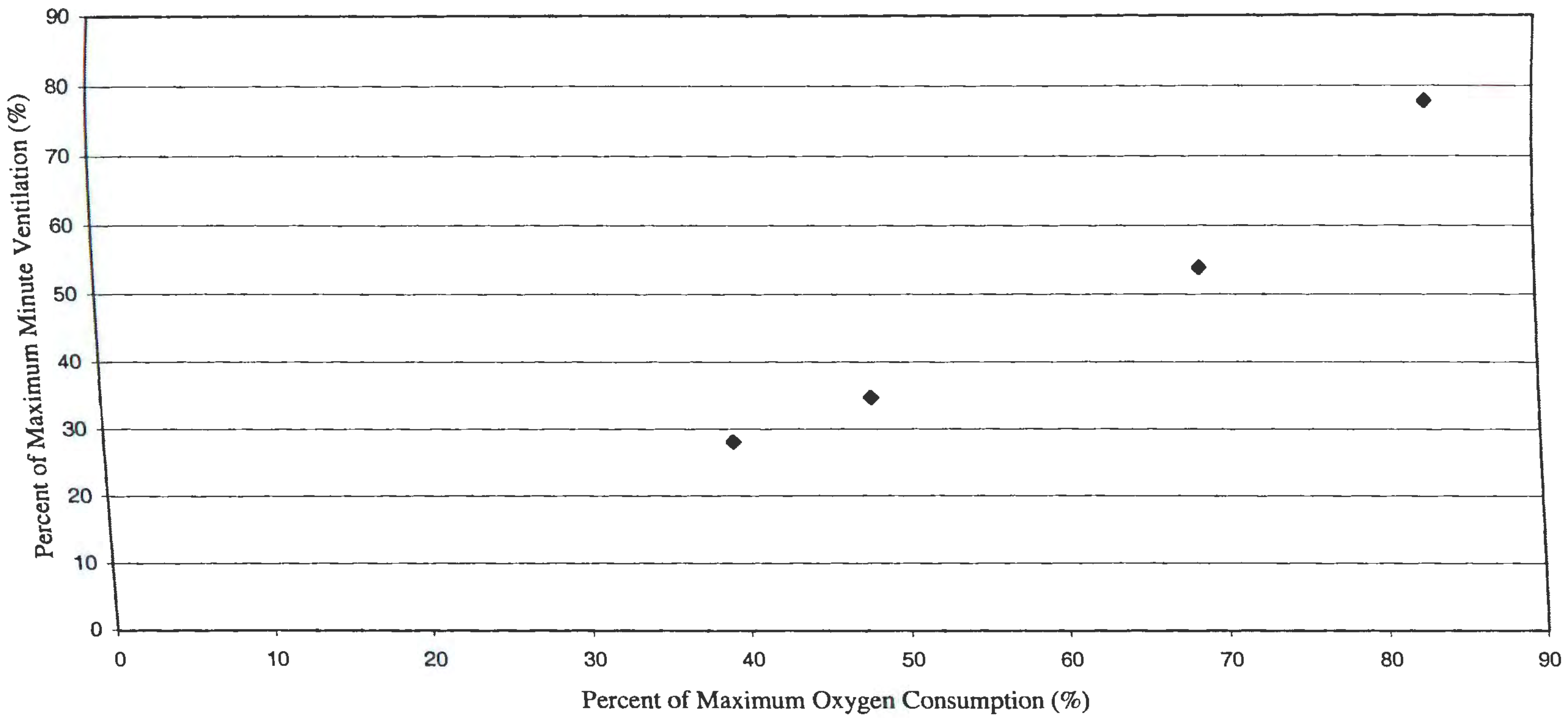


Figure 84. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 001.

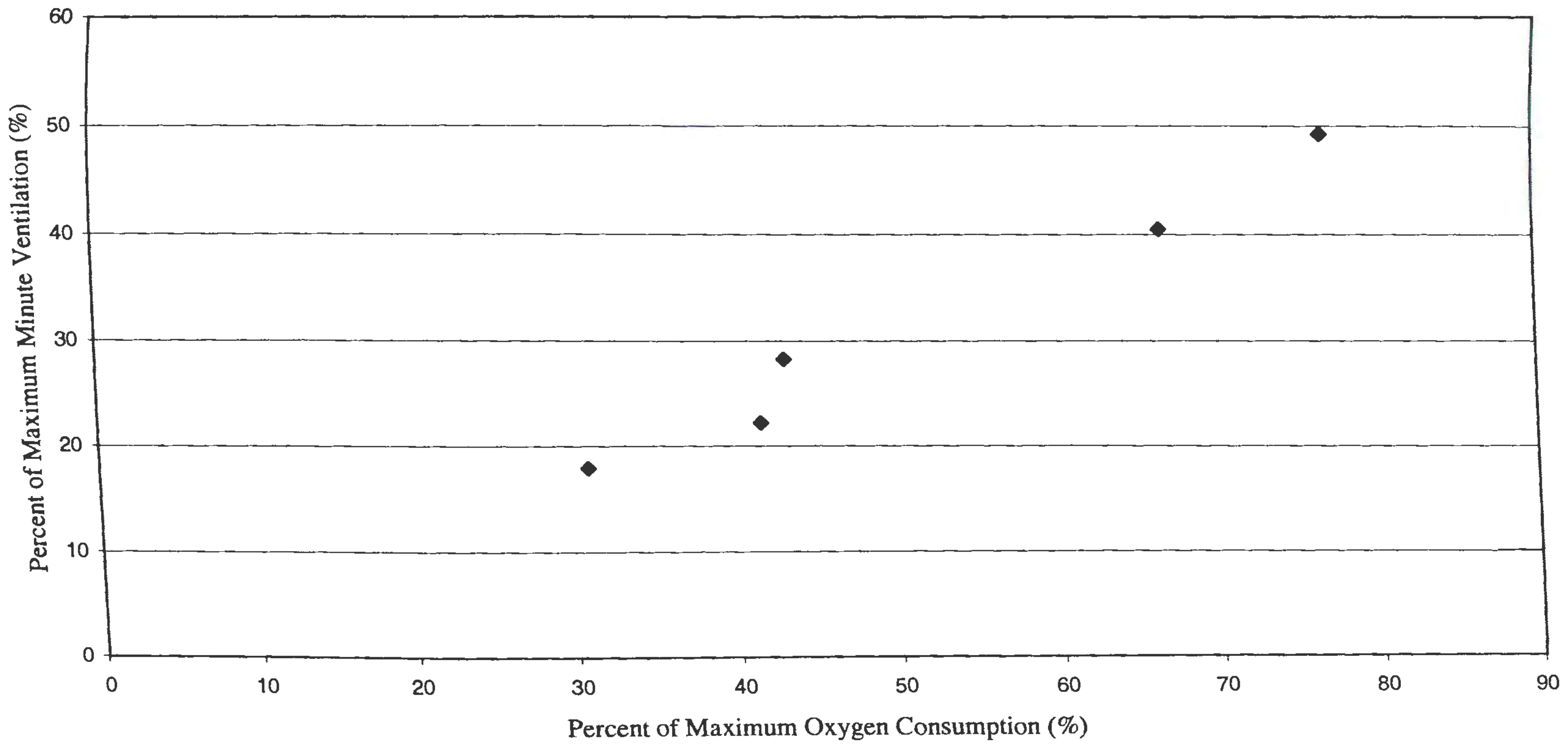


Figure 85. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 002.

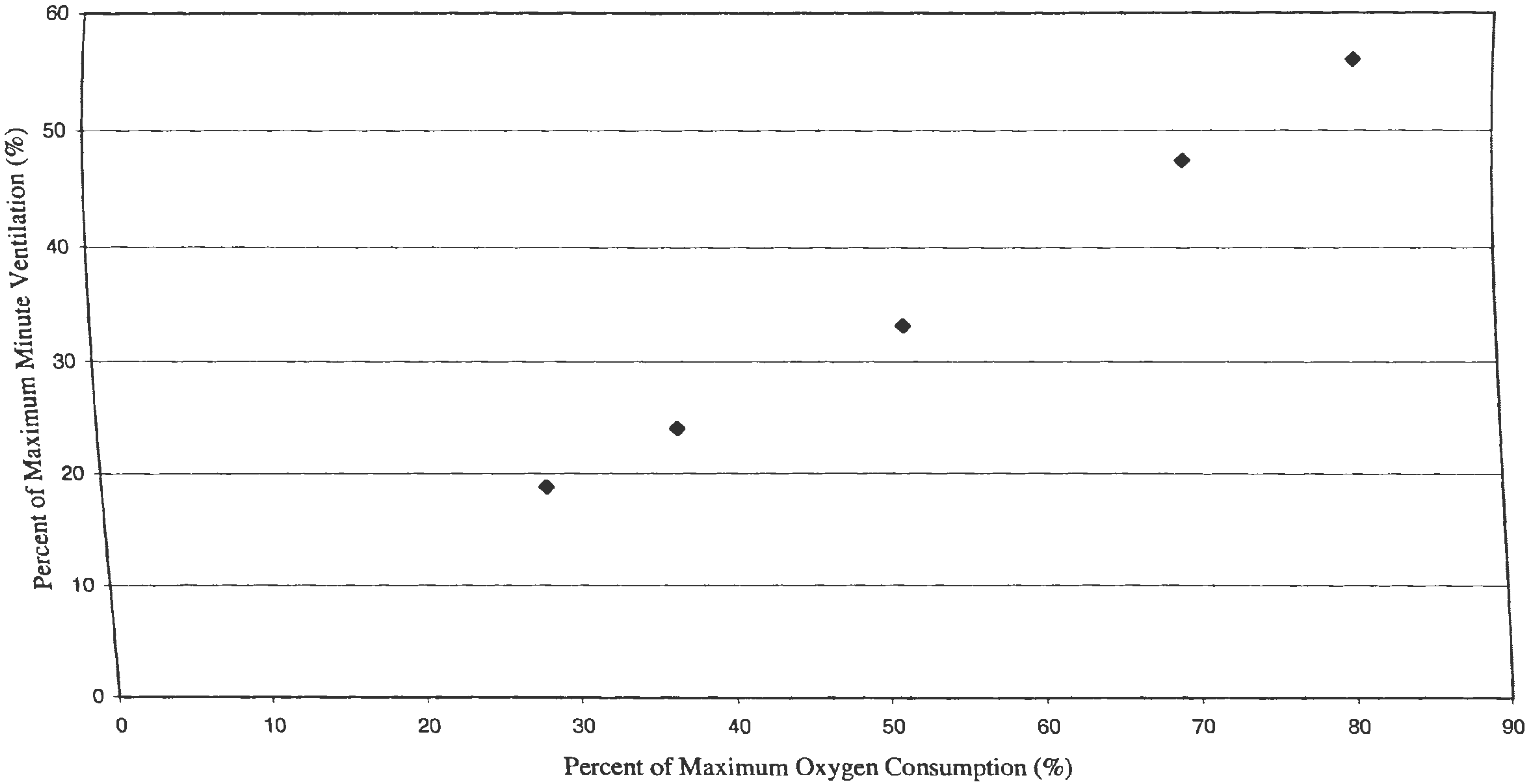


Figure 86. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 023.

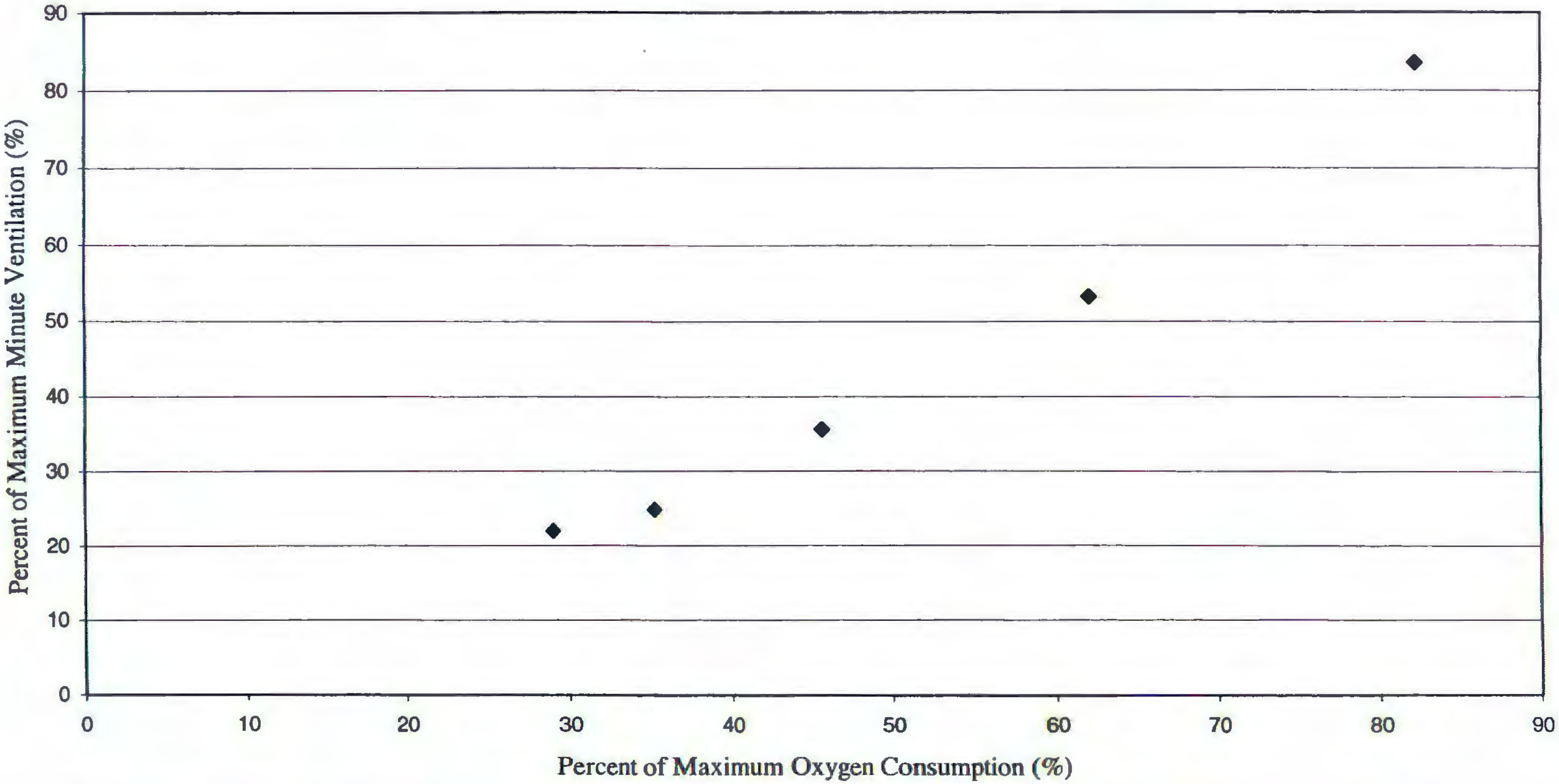


Figure 87. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 145.

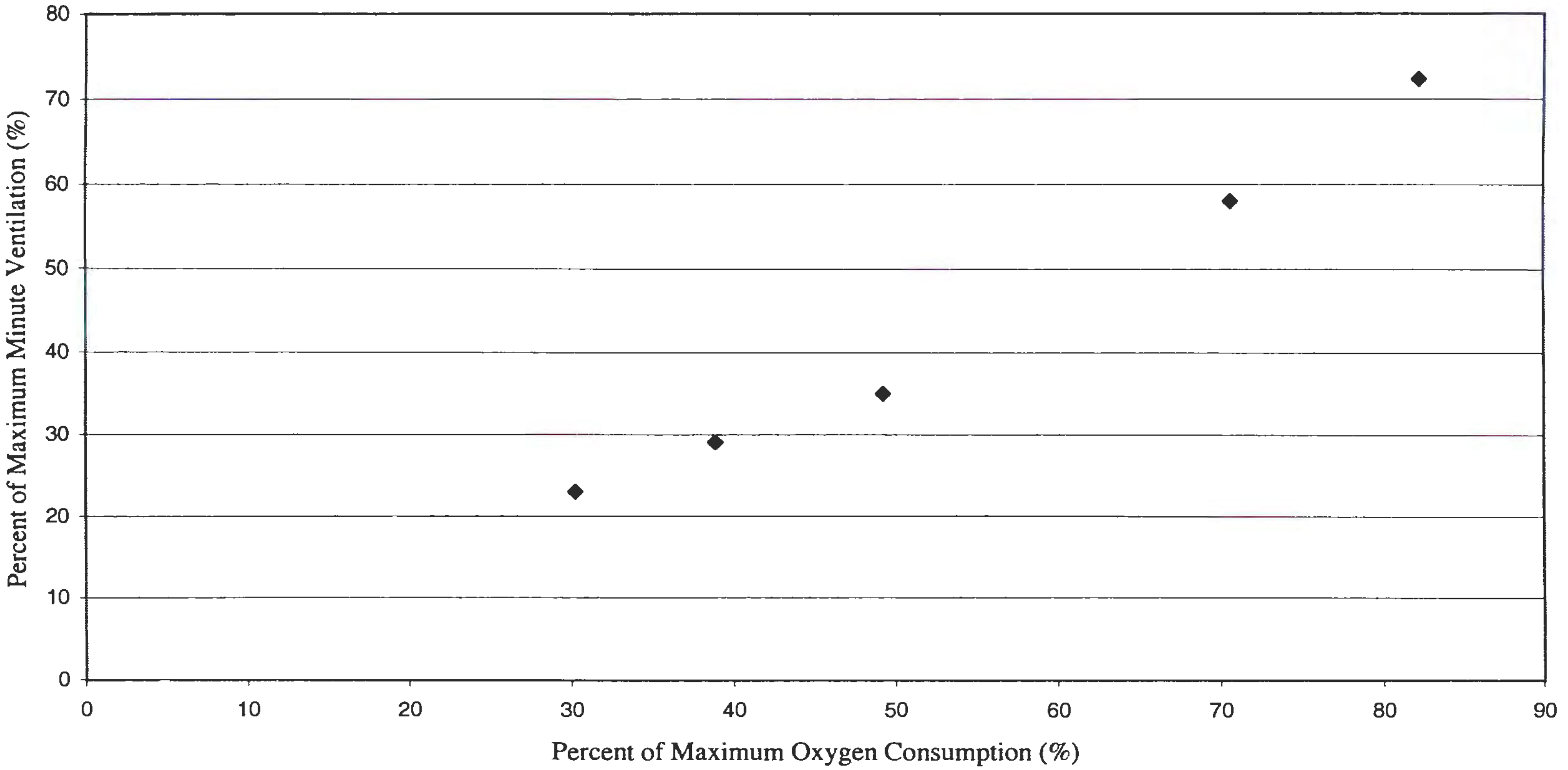


Figure 88. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 173.

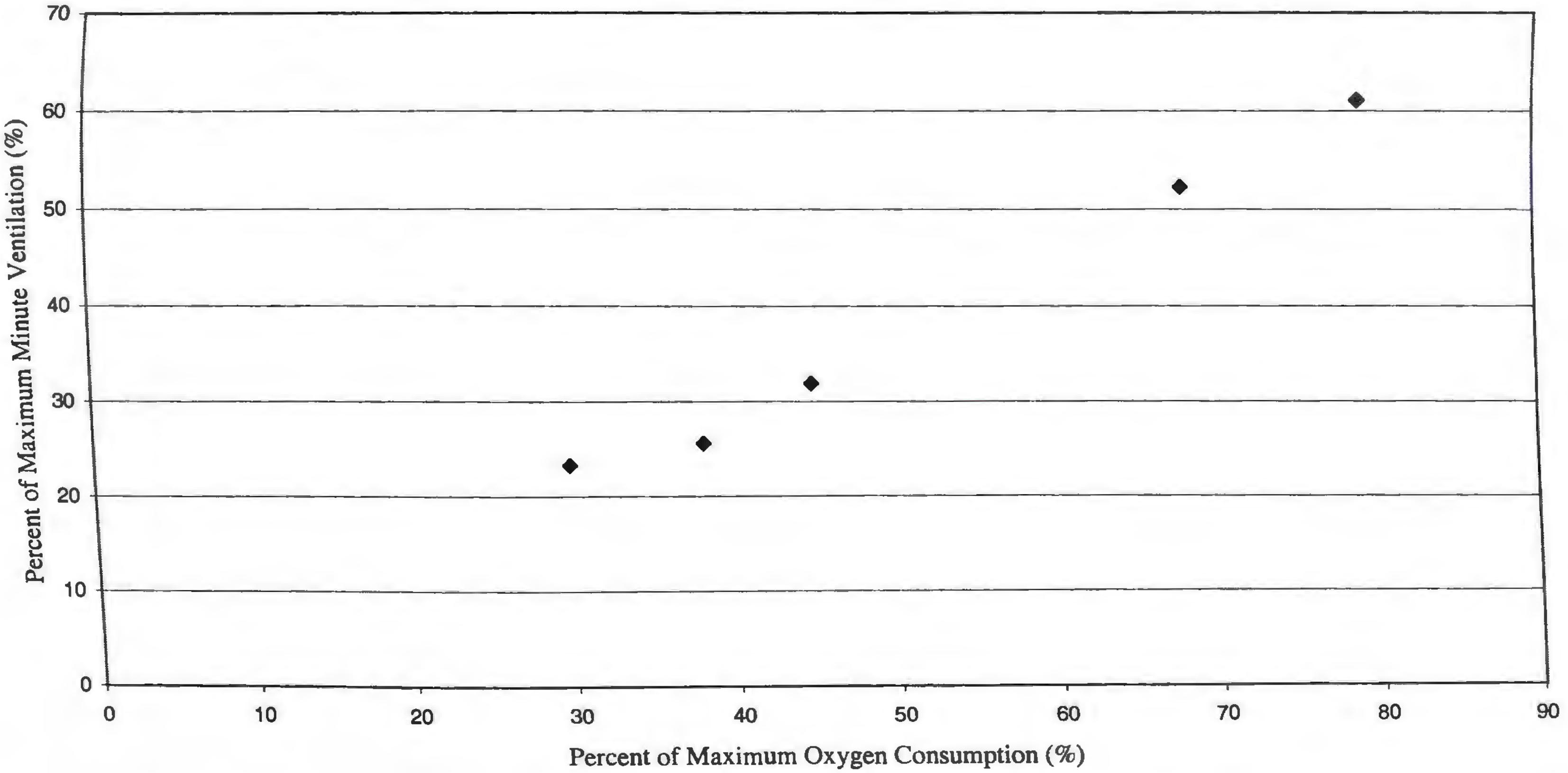


Figure 89. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 214.

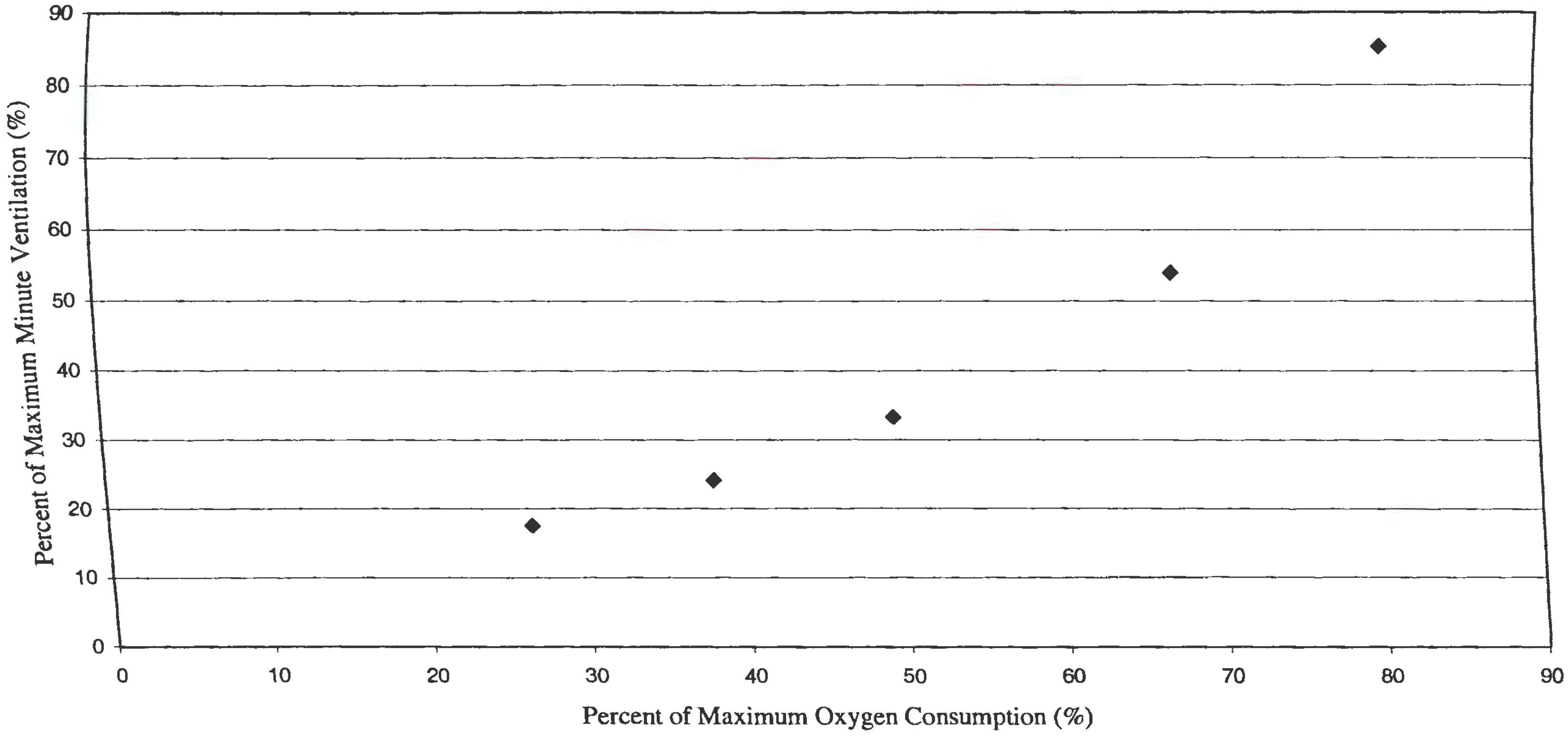


Figure 90. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 221.

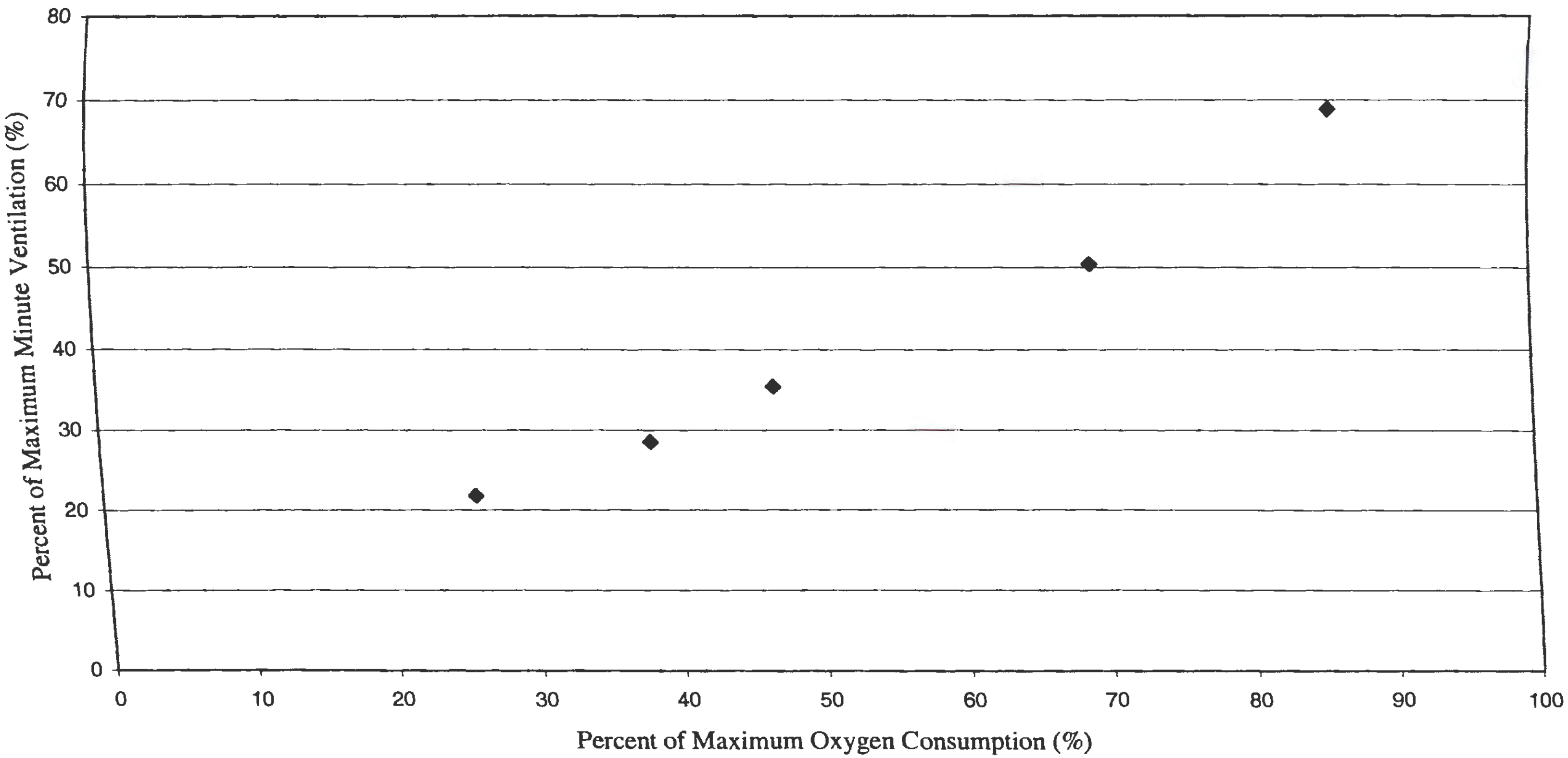


Figure 91. Percent of maximum minute ventilation versus percent of maximum oxygen consumption obtained during the levels determination session for subject 231.

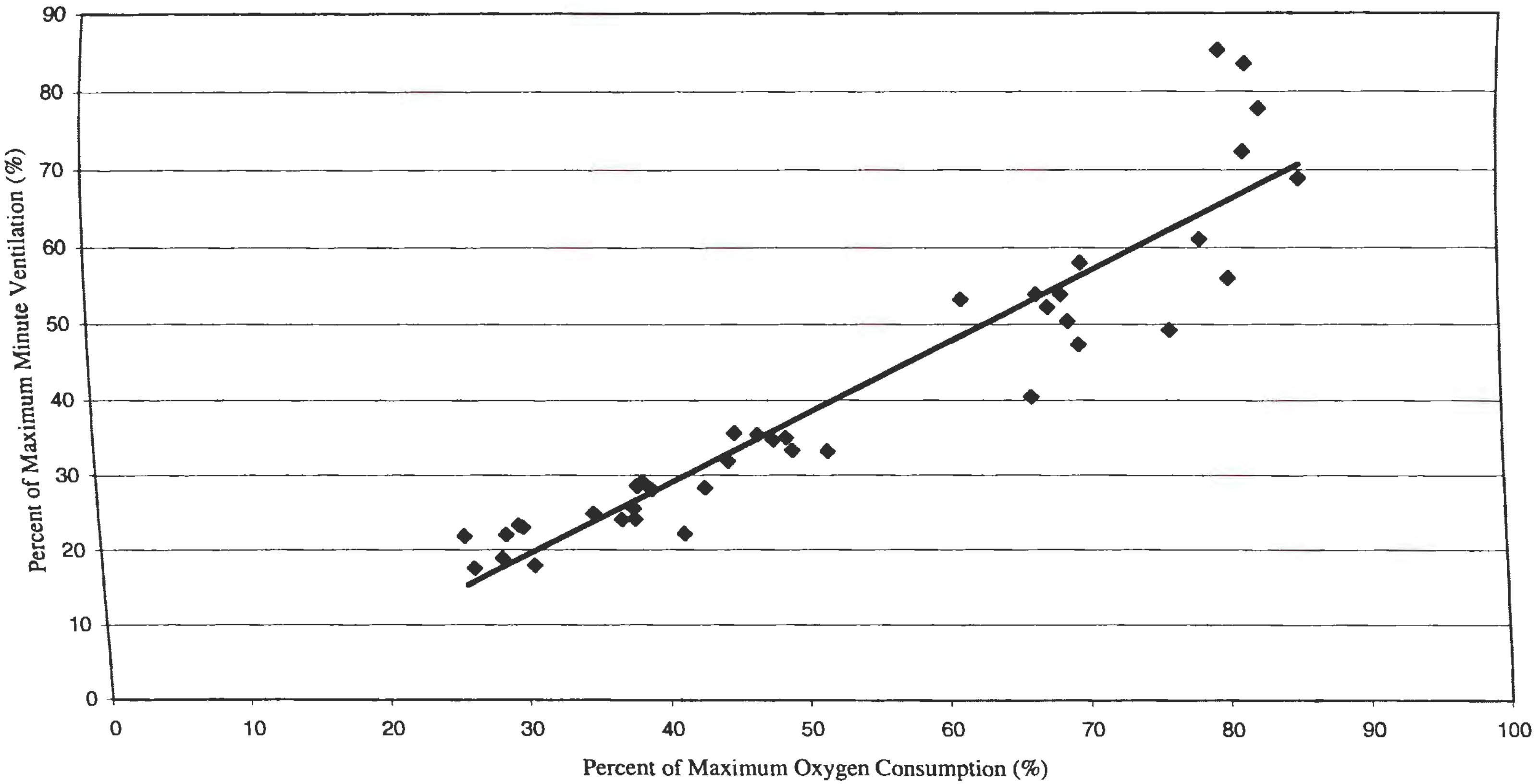


Figure 92. Percent of maximum minute ventilation versus percent of maximum oxygen consumption for all subjects combined. Shown is the best-fit linear model.

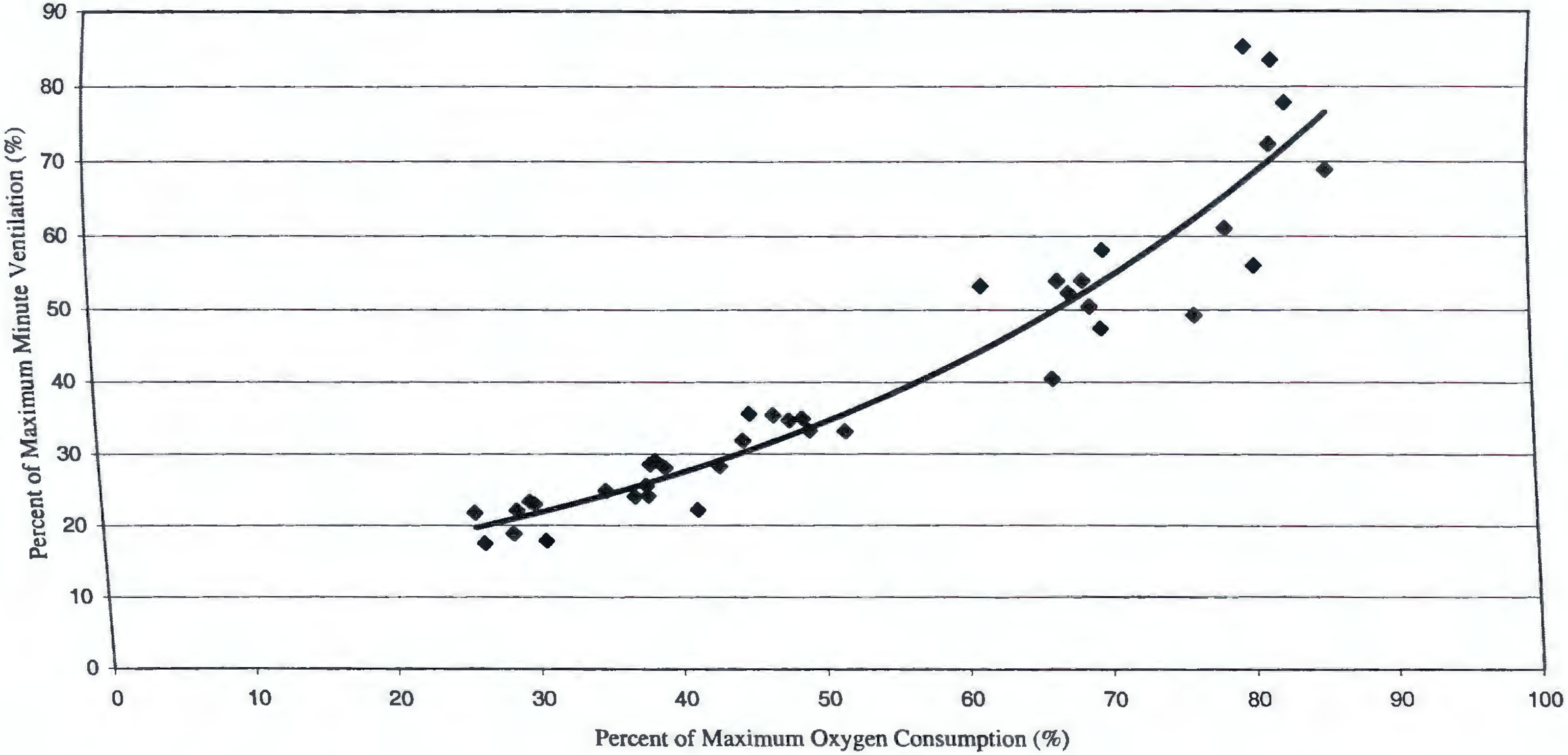


Figure 93. Percent of maximum minute ventilation versus percent of maximum oxygen consumption for all subjects combined. Shown is the best-fit exponential model.

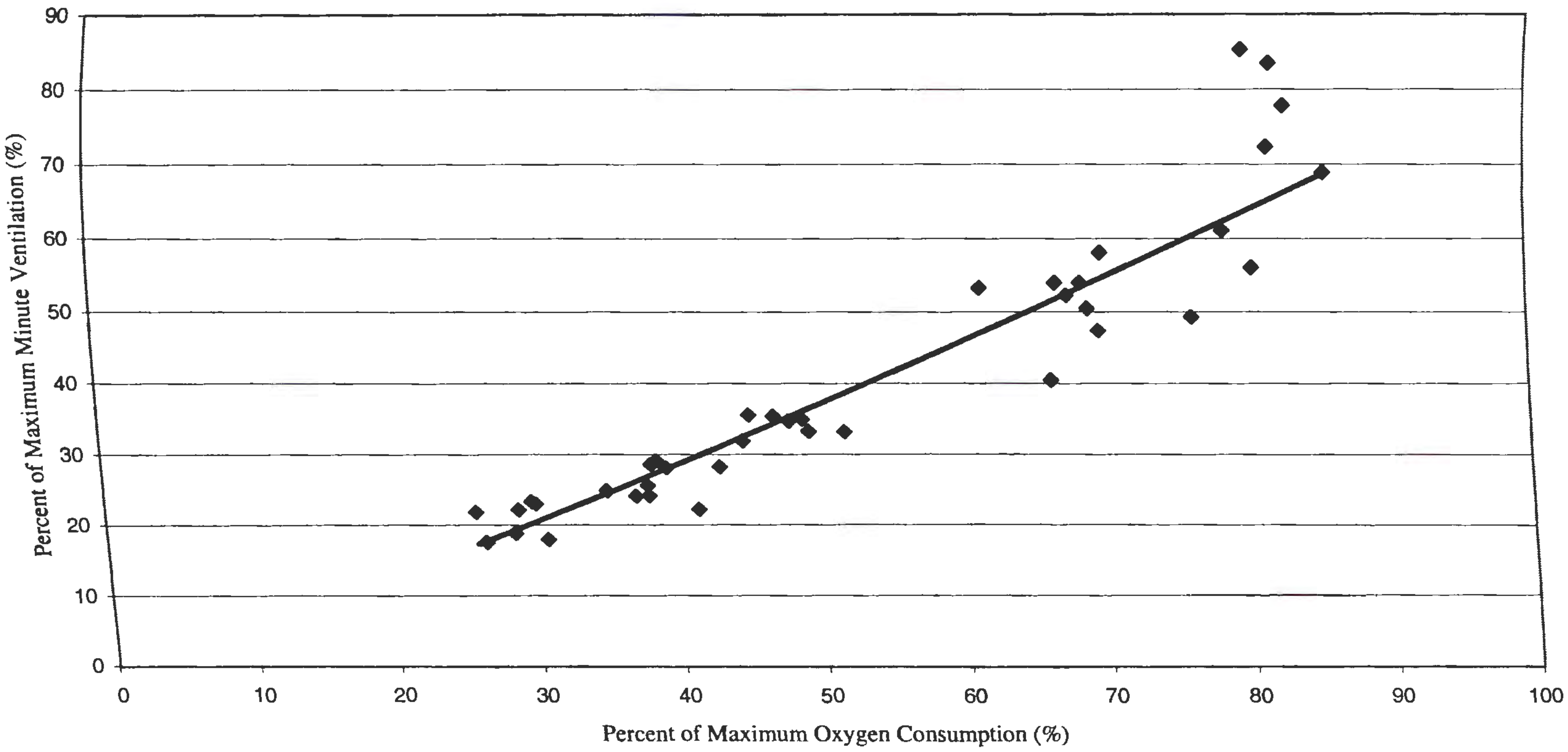


Figure 94. Percent of maximum minute ventilation versus percent of maximum oxygen consumption for all subjects combined. Shown is the best-fit power model.

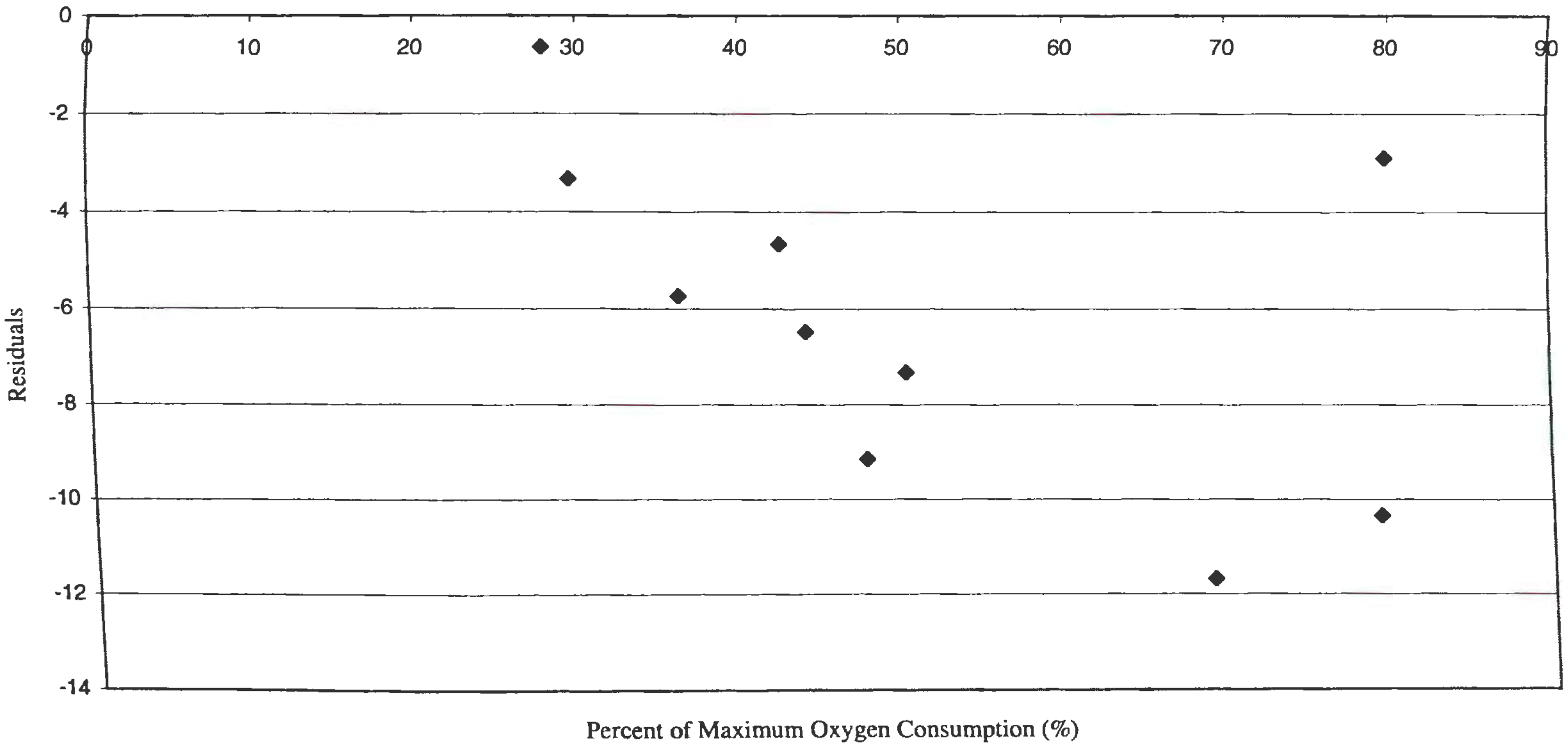


Figure 95. Residuals of percent of maximum minute ventilation of the validation data.

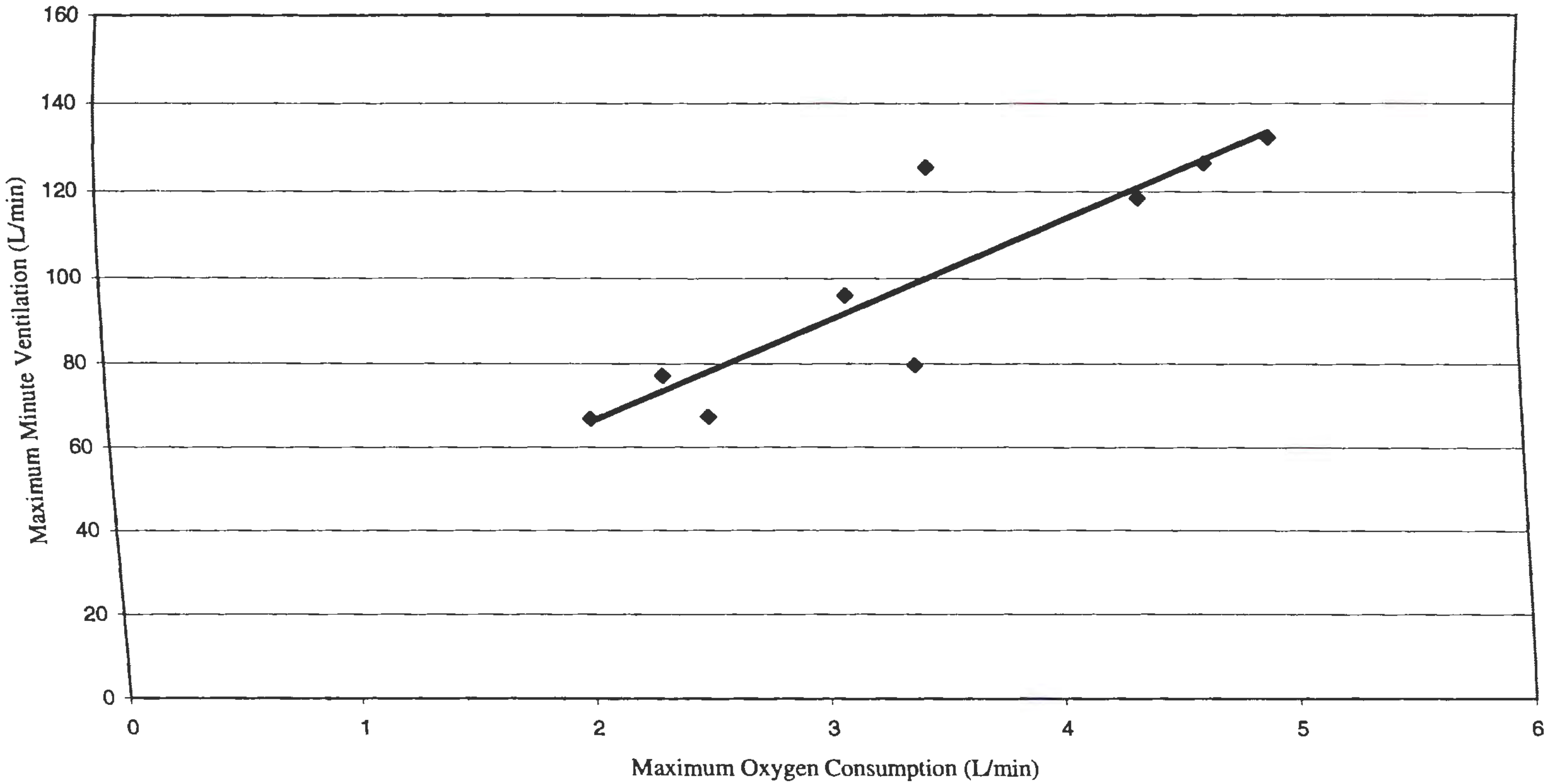


Figure 96. Maximum minute ventilation and maximum oxygen consumption data from the current study. Shown is the best fit line.

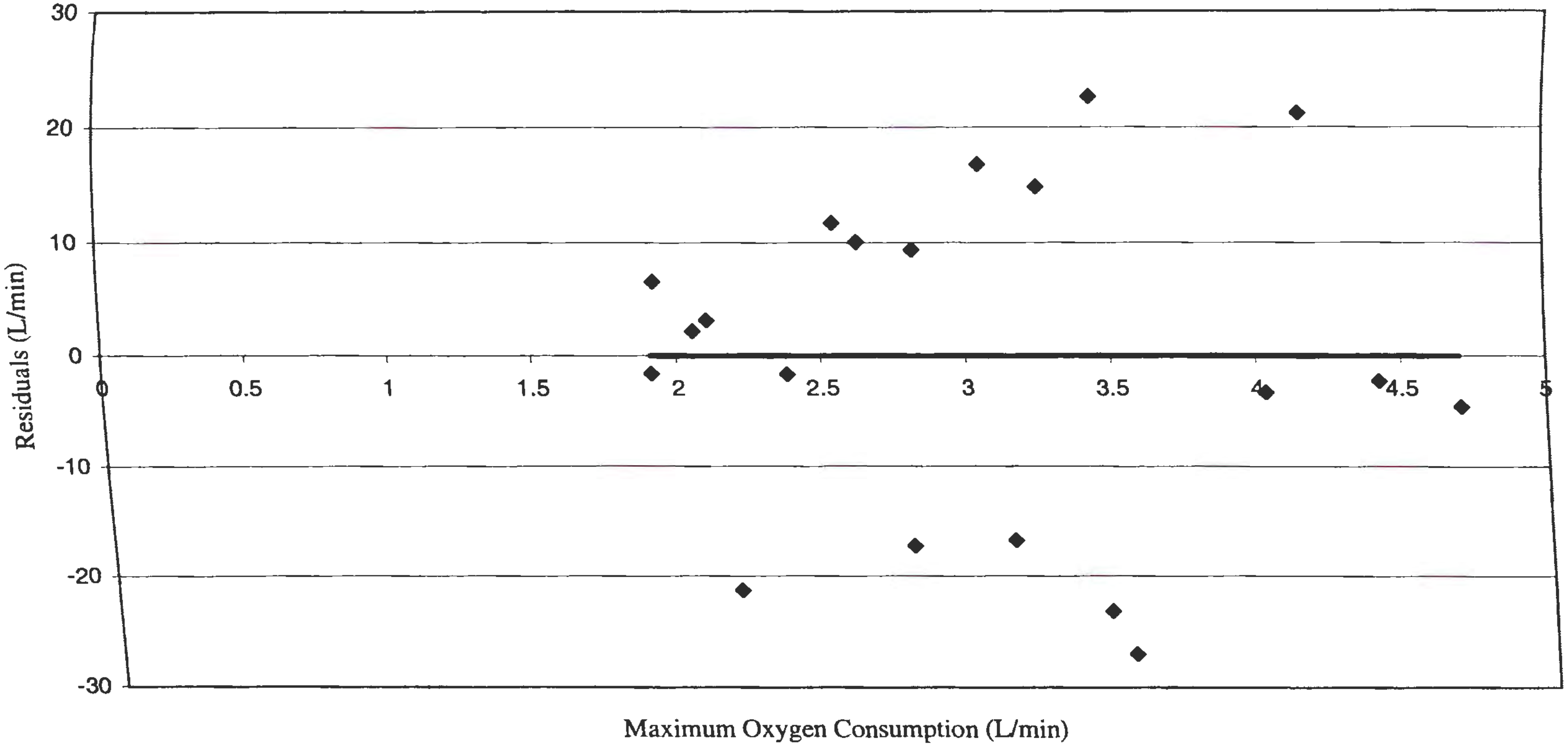


Figure 97. Residuals of maximum minute ventilation for the calibration data.

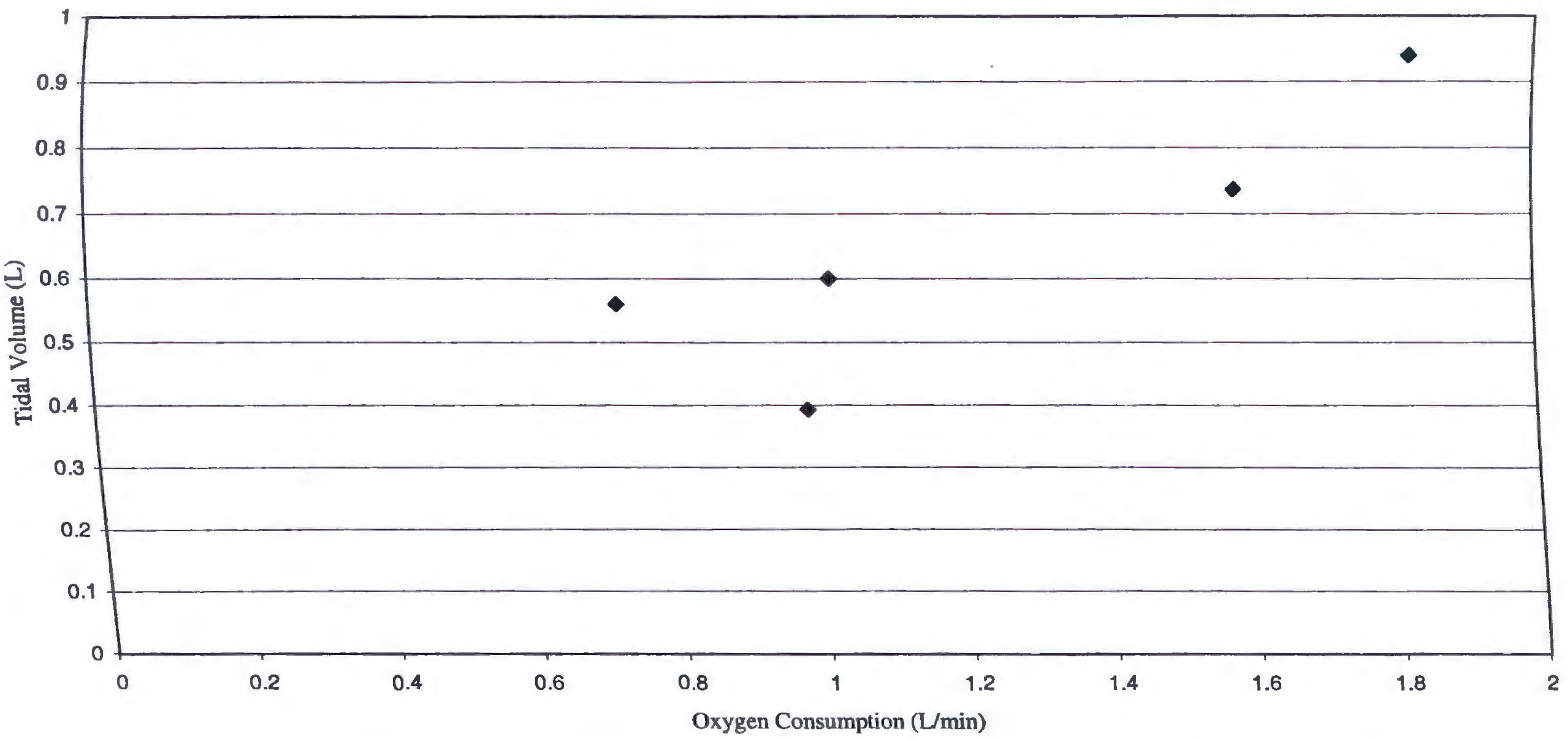


Figure 98. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 002.

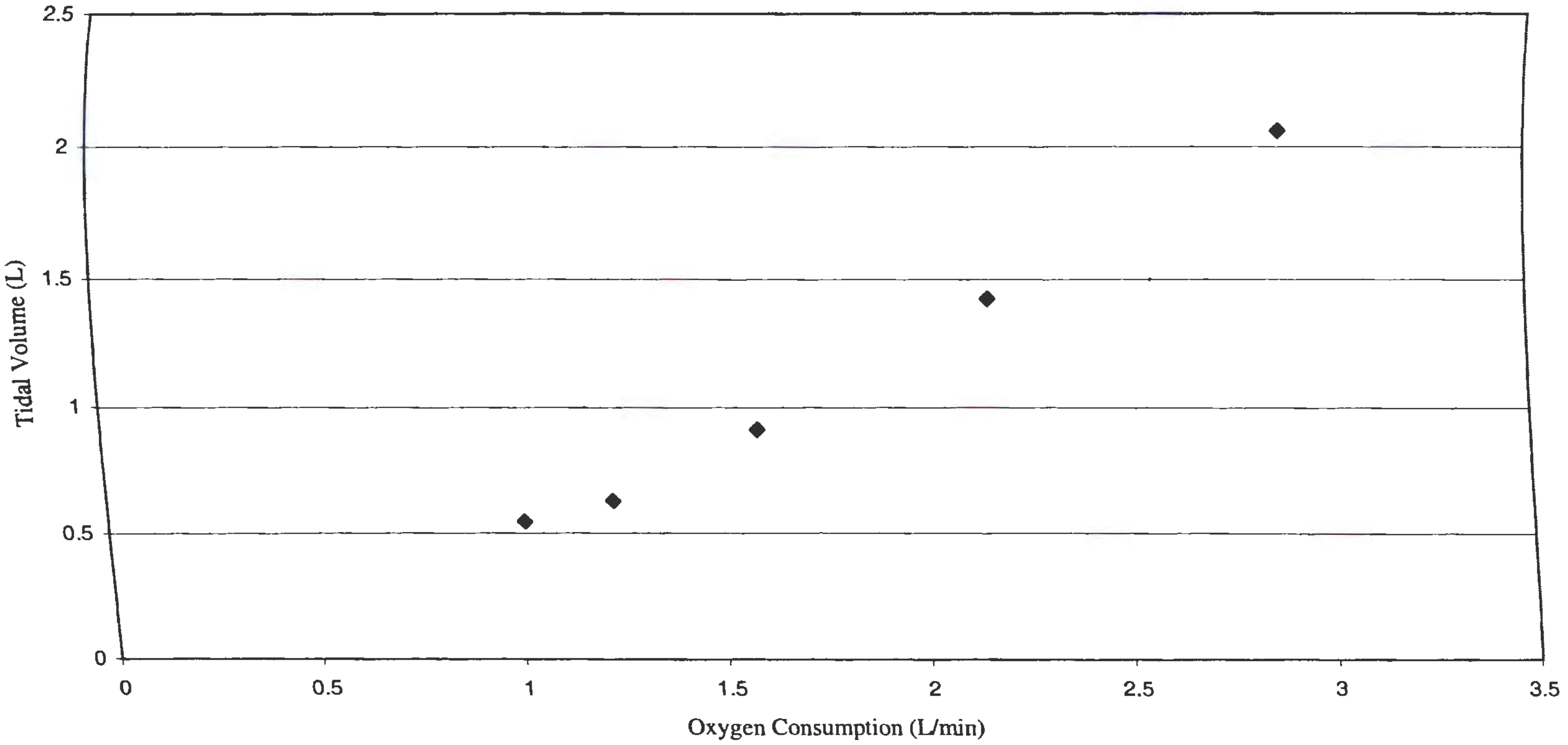


Figure 99. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 145.

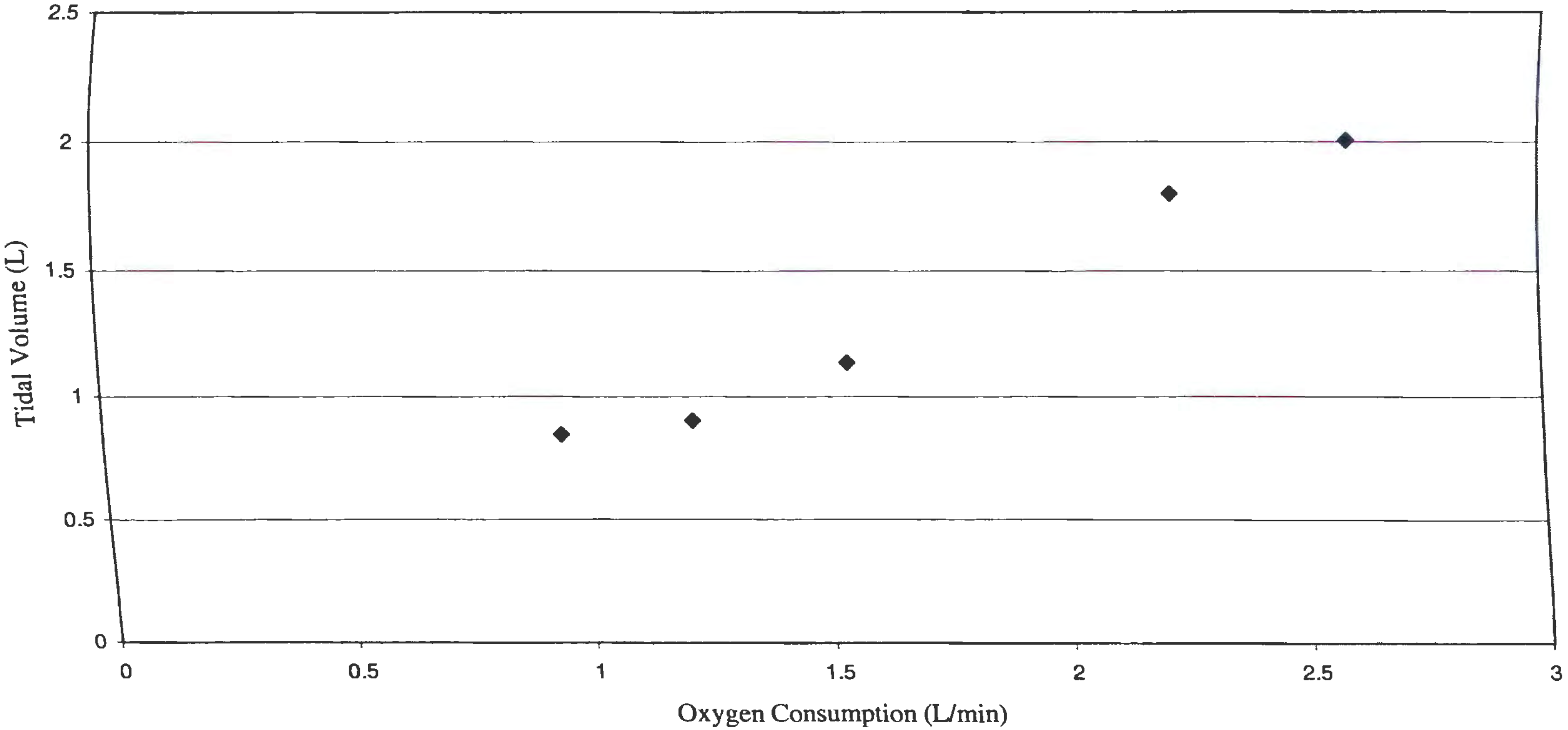


Figure 100. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 173.

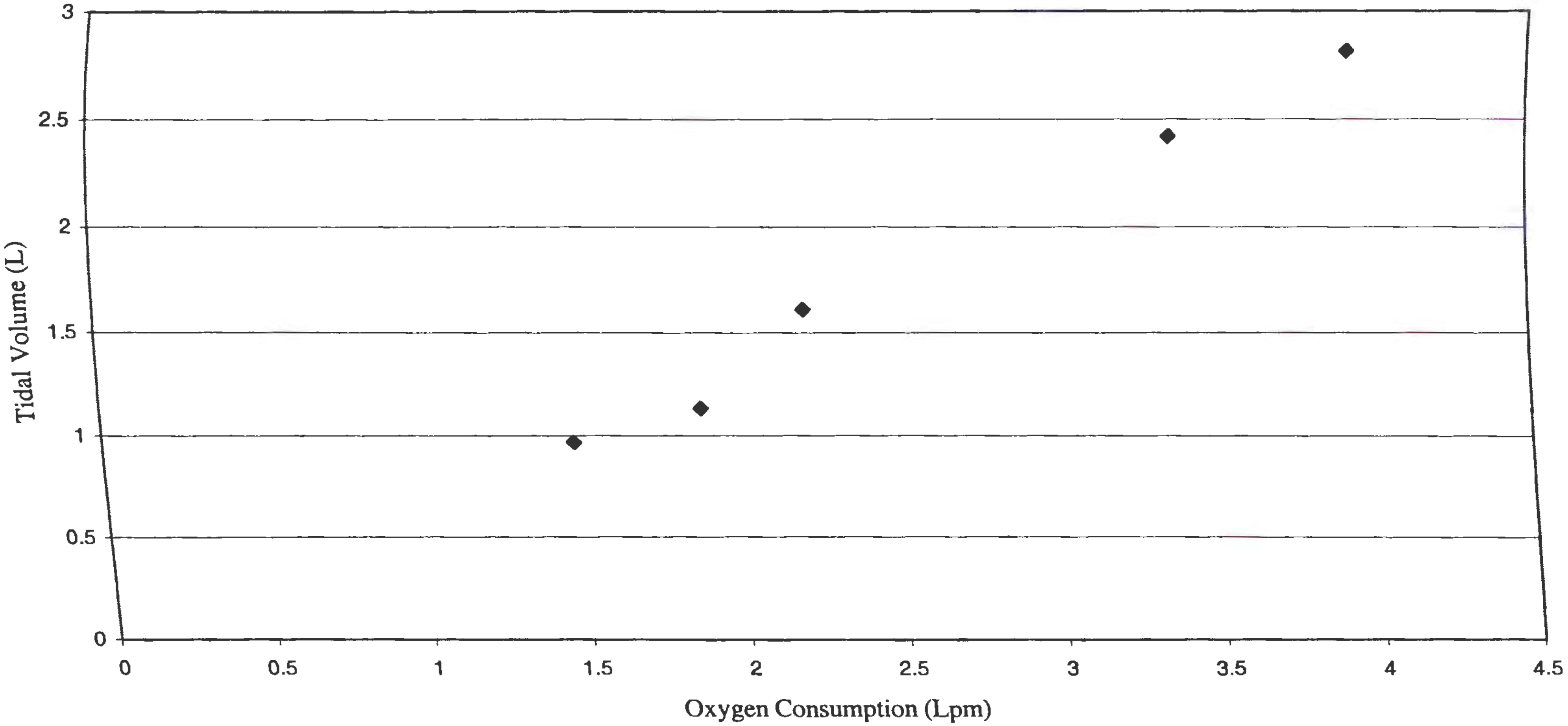


Figure 101. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 214.

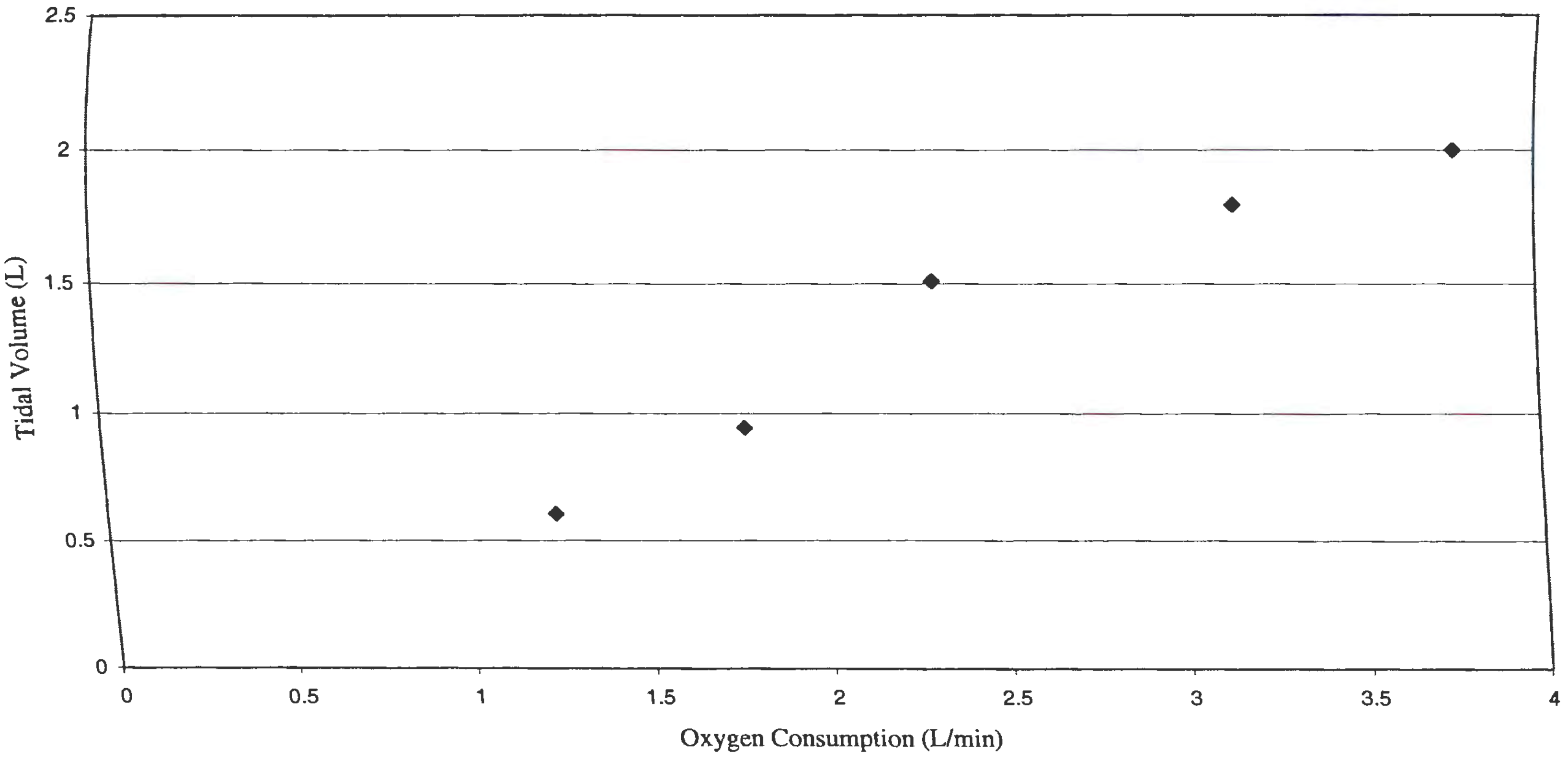


Figure 102. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 221.

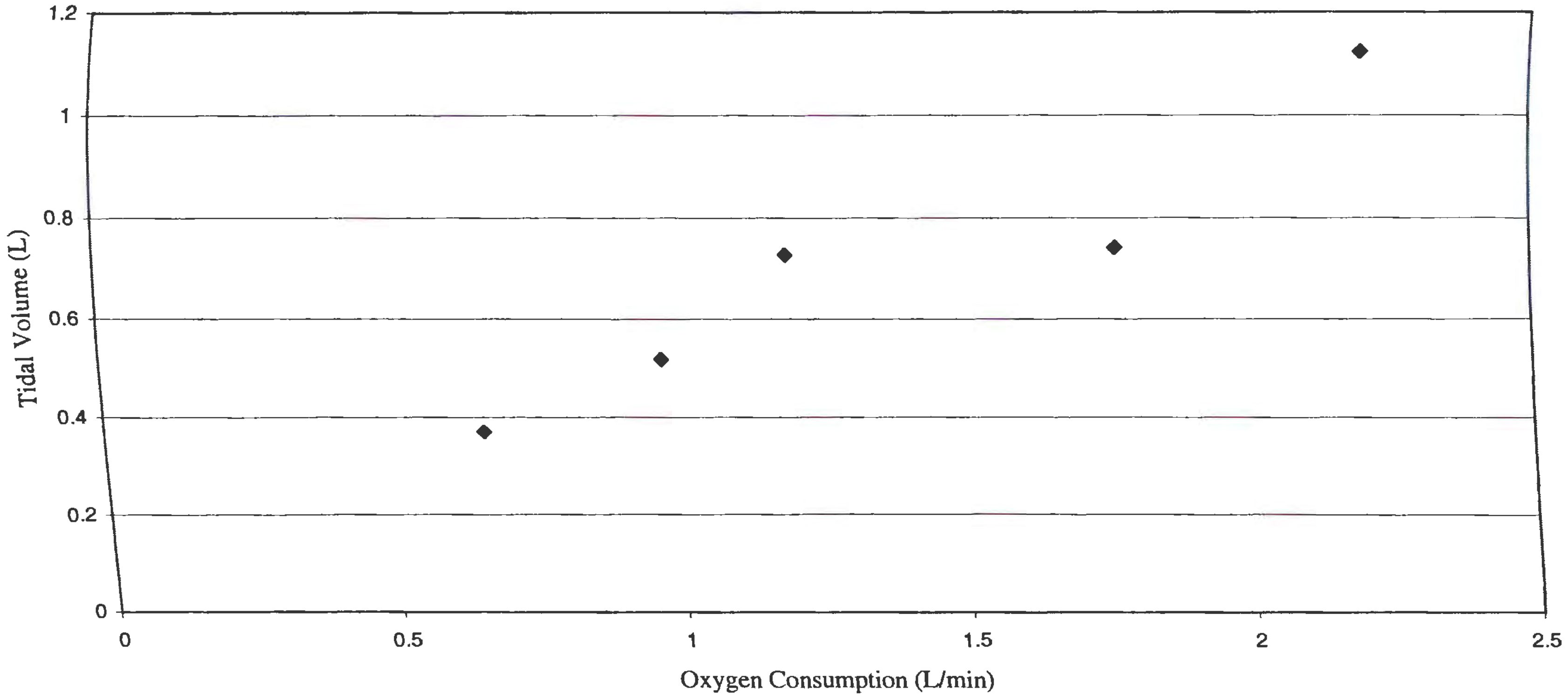


Figure 103. Steady-state tidal volume versus oxygen consumption obtained during the levels determination session for subject 231.

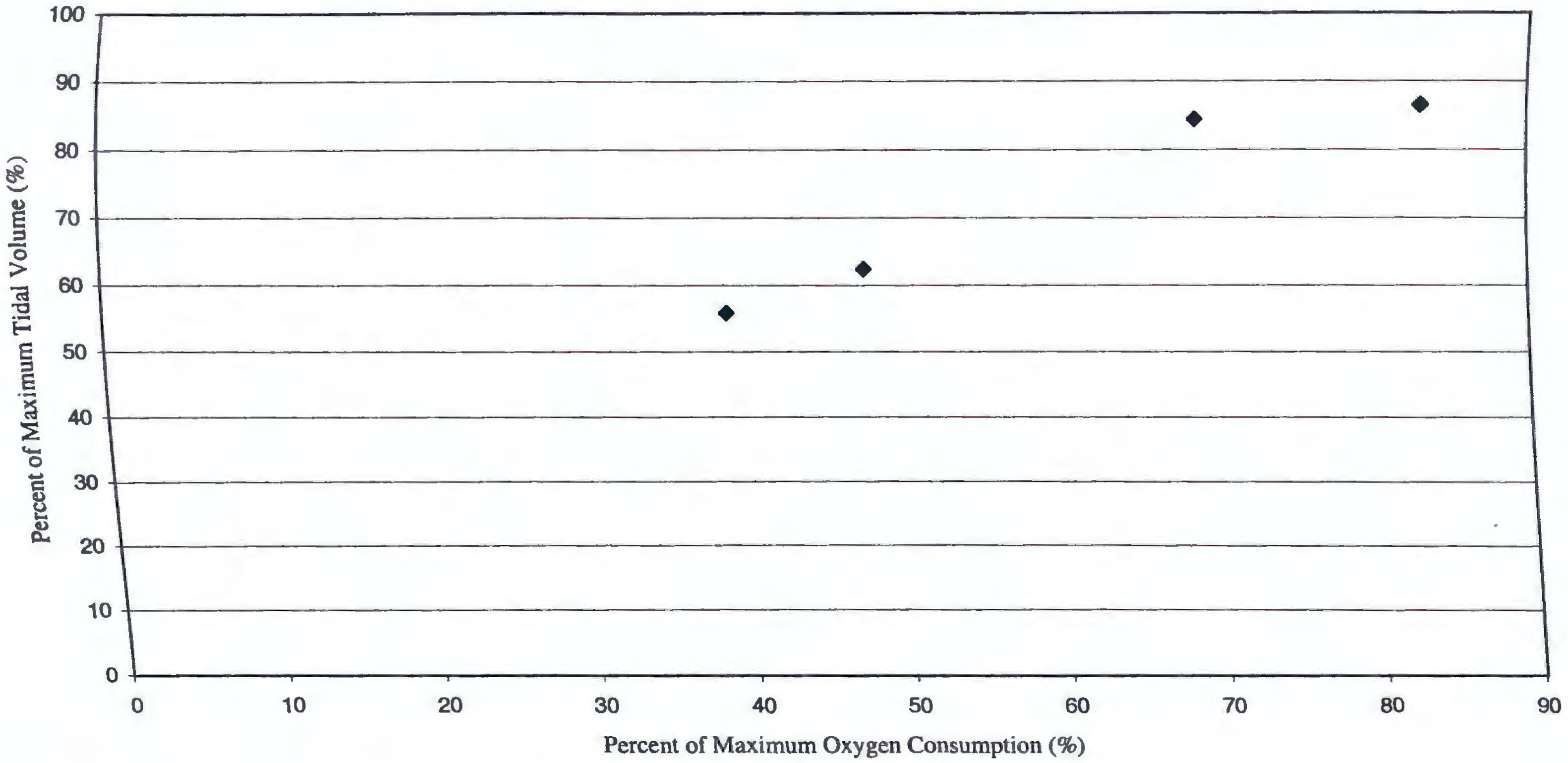


Figure 104. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 001.

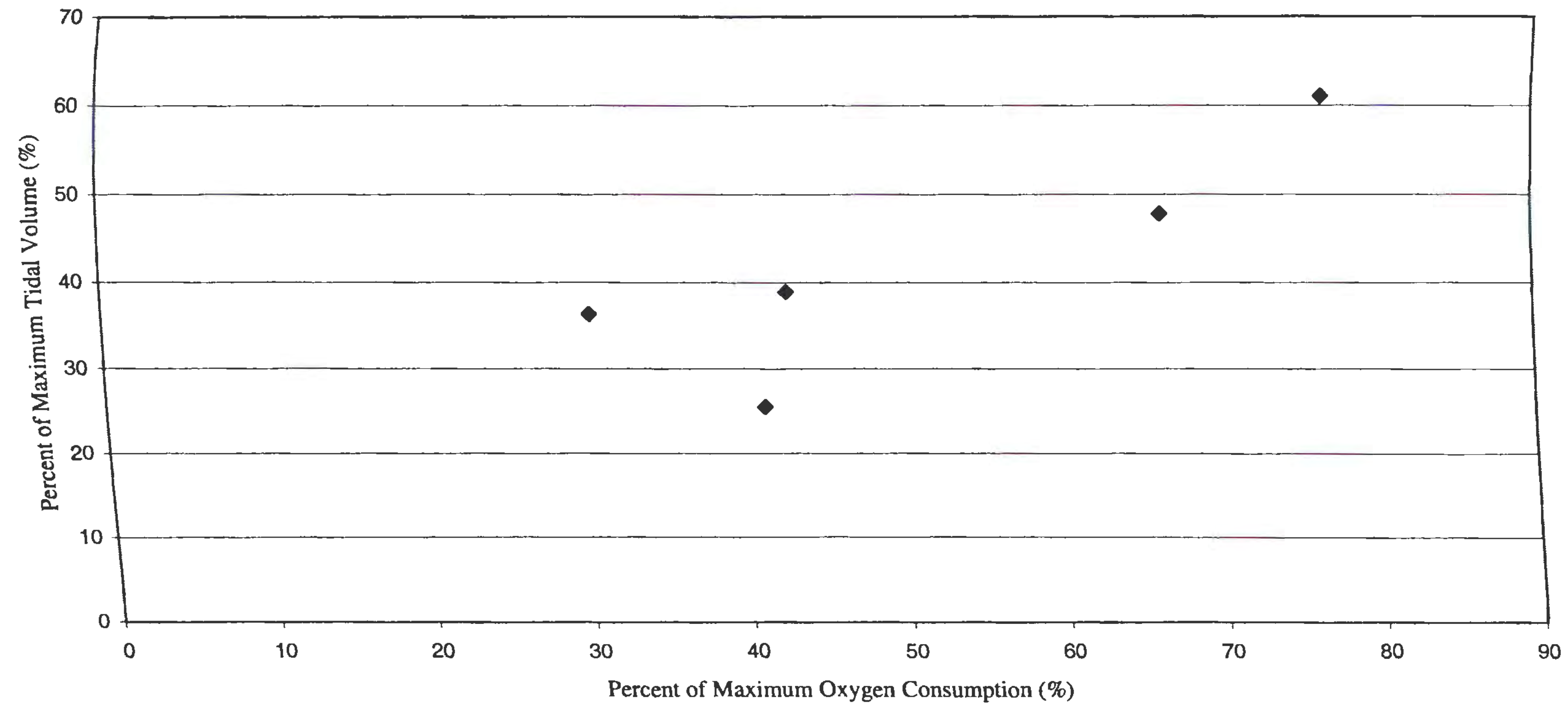


Figure 105. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 002.

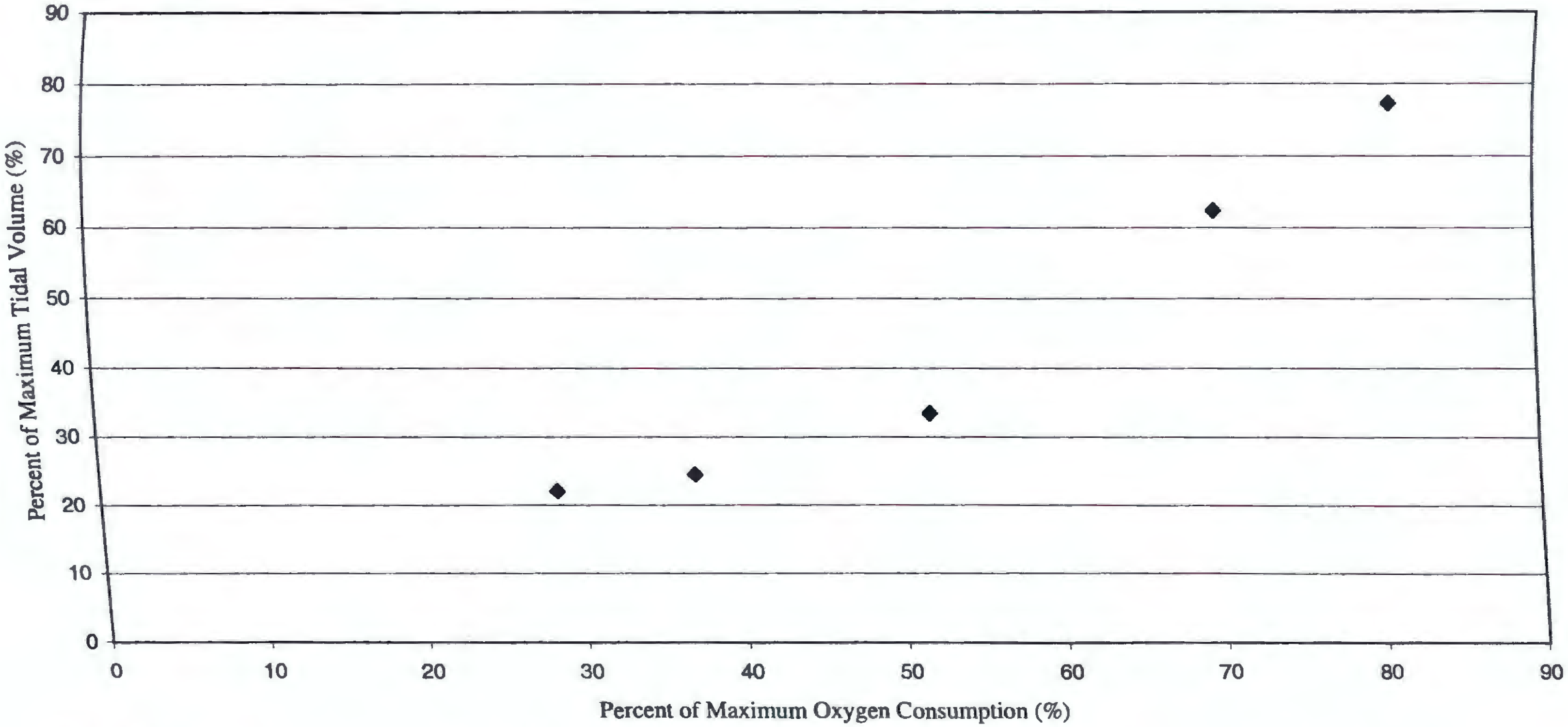


Figure 106. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 023.

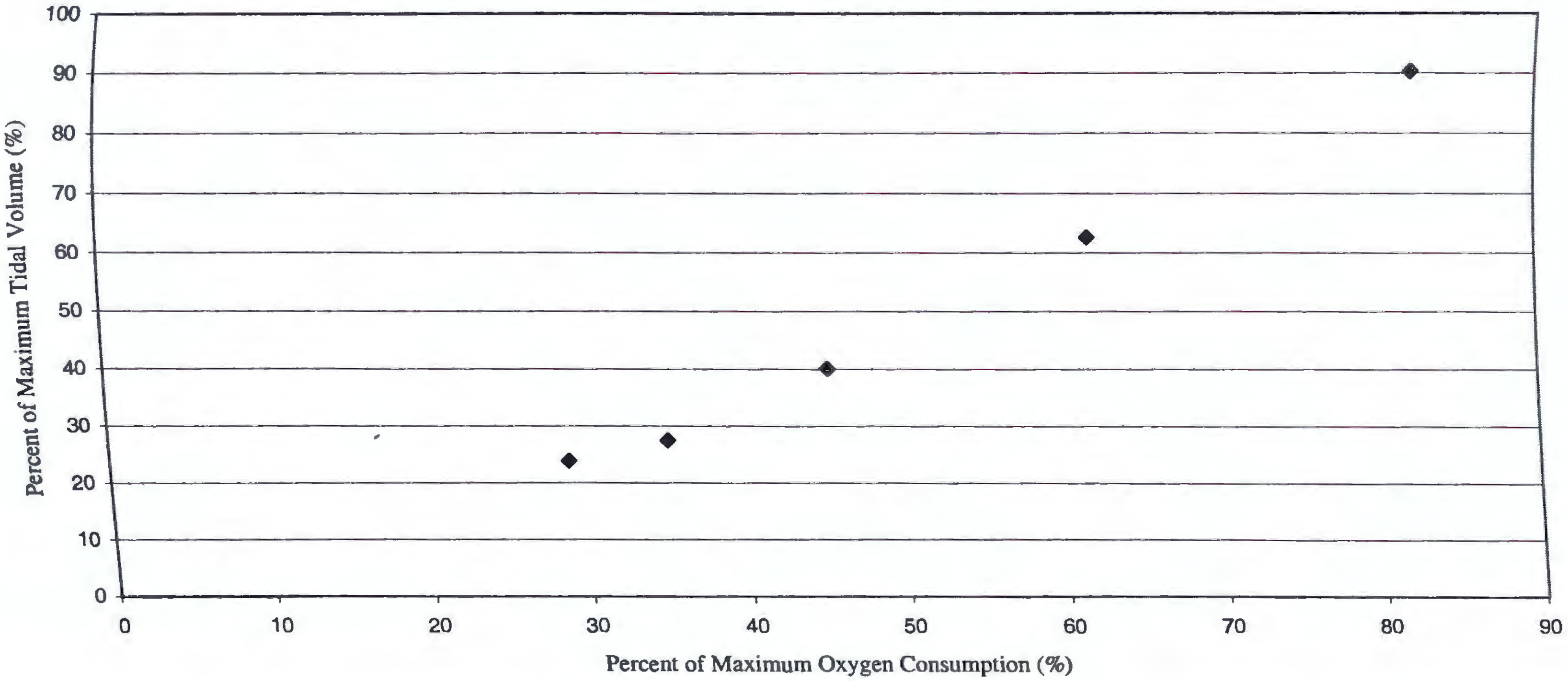


Figure 107. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 145.

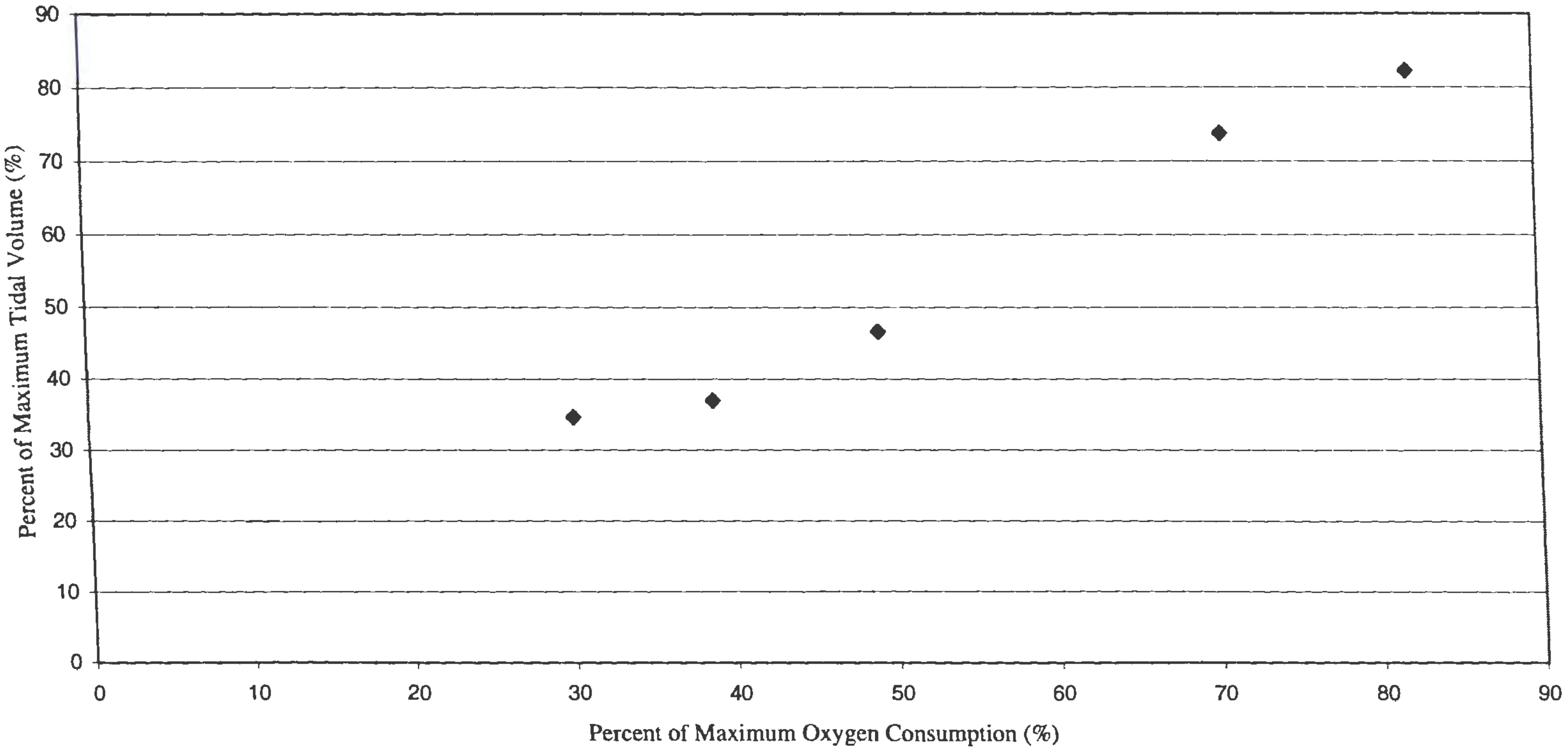


Figure 108. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 173.

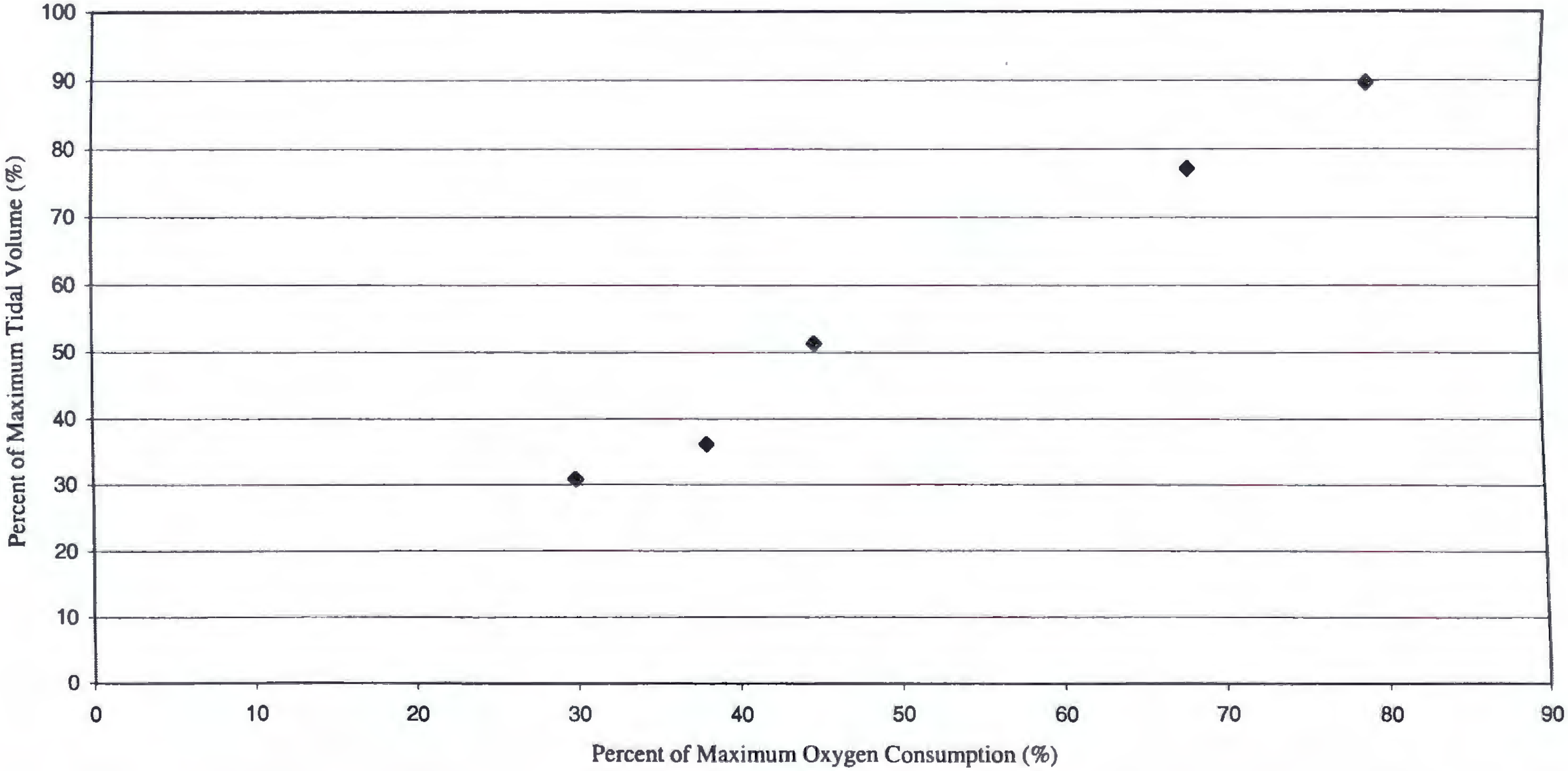


Figure 109. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 214.

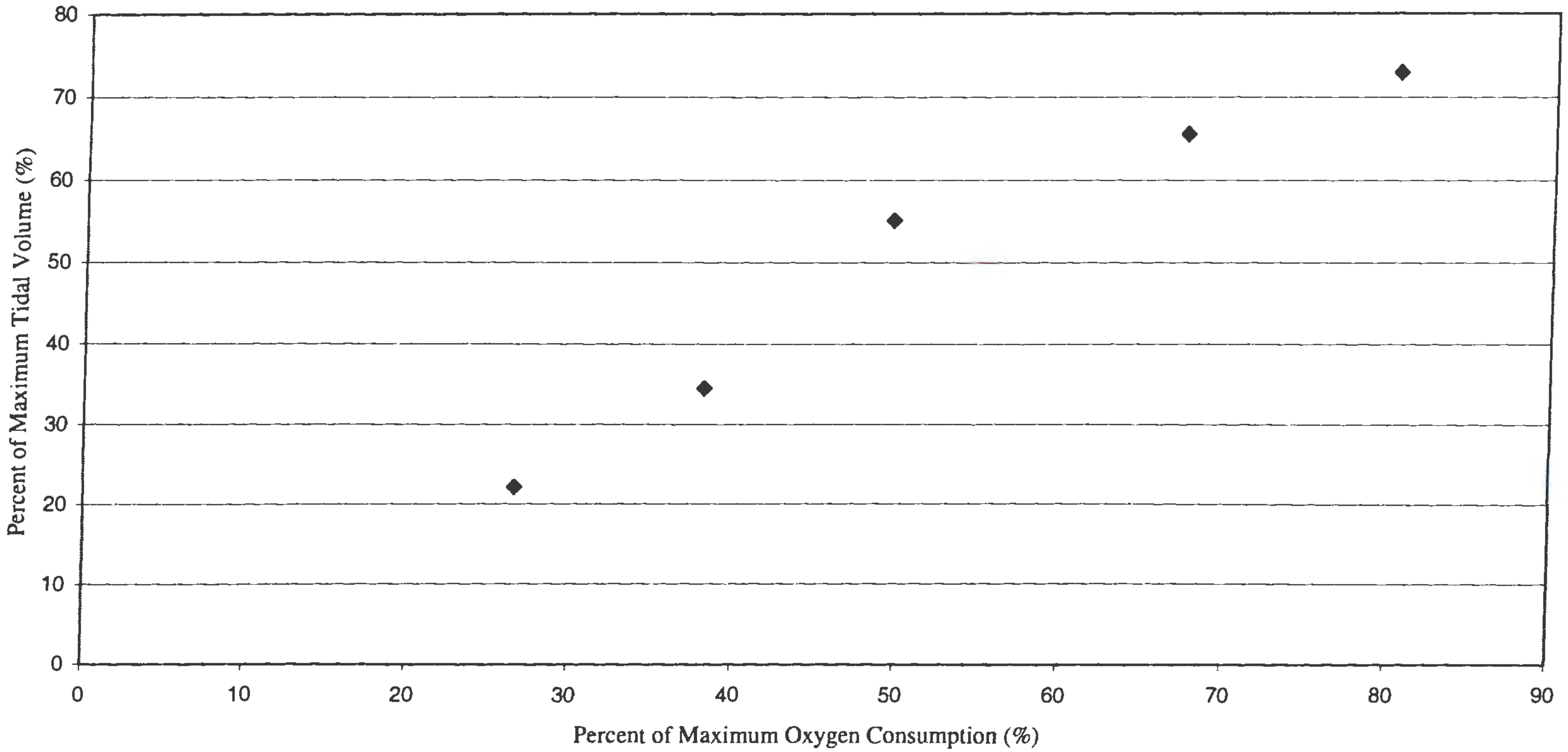


Figure 110. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 221.

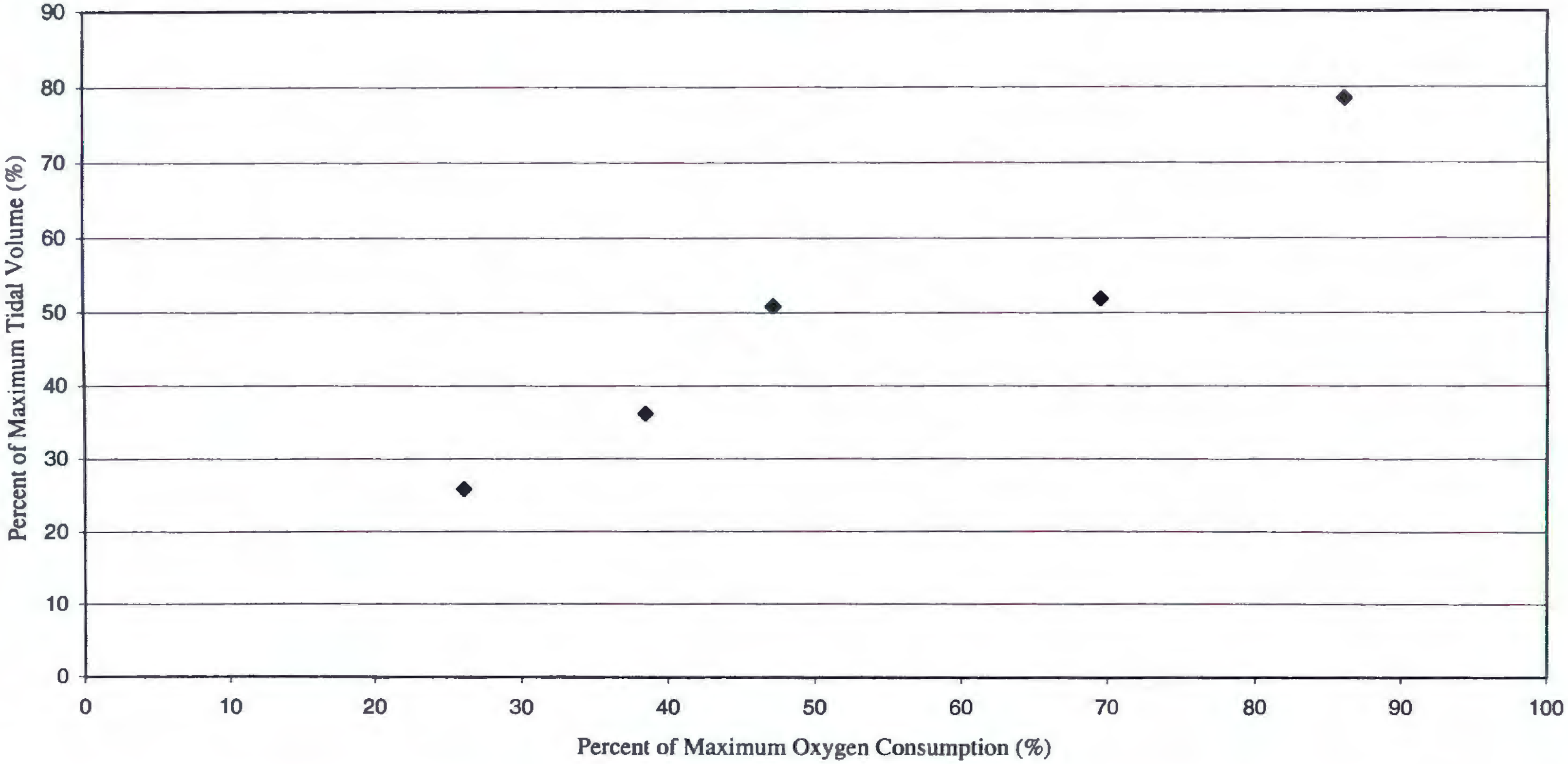


Figure 111. Percent of maximum tidal volume versus percent of maximum oxygen consumption obtained during the levels determination session for subject 231.

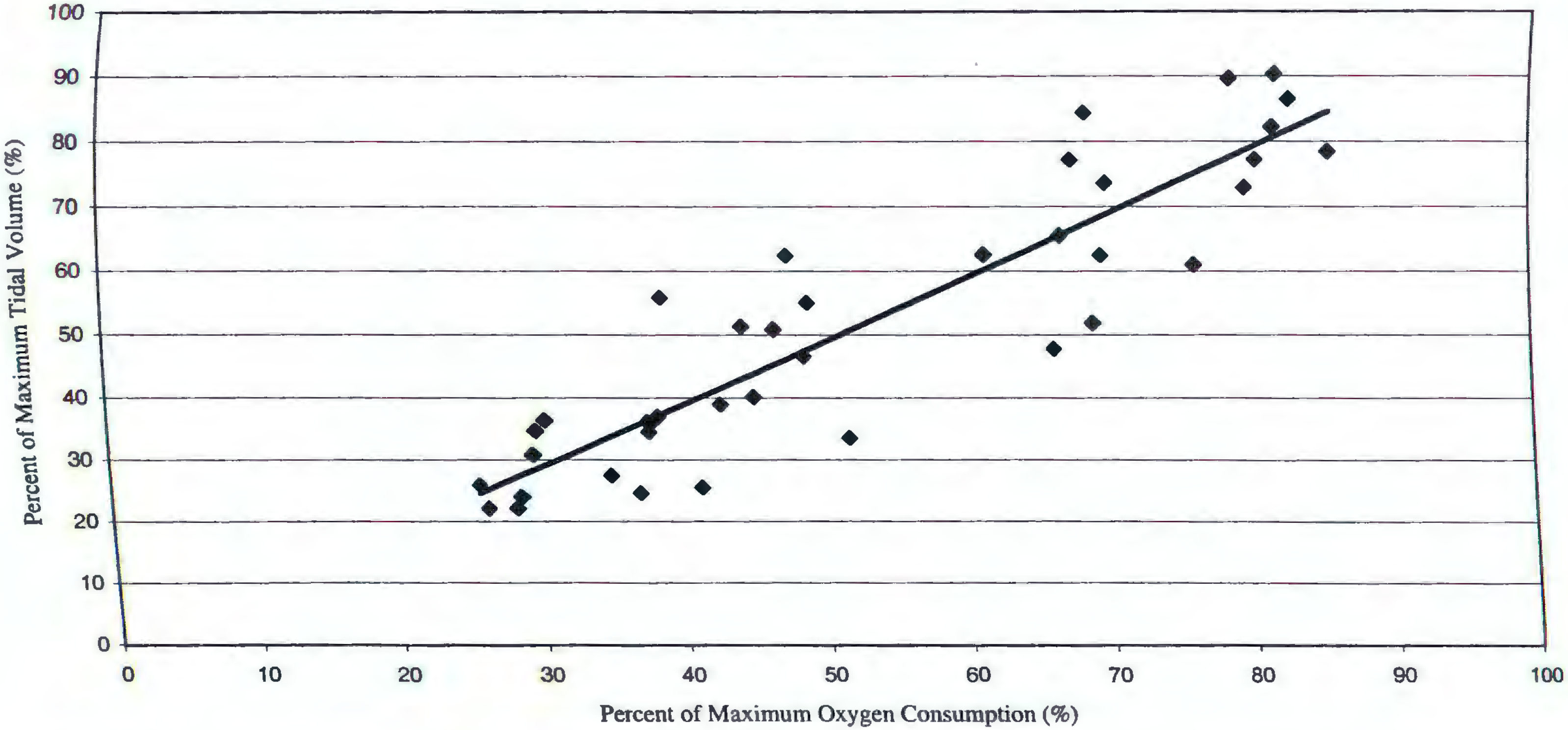


Figure 112. Quadratic model fit to the pooled data from the eight subjects who completed the current study.

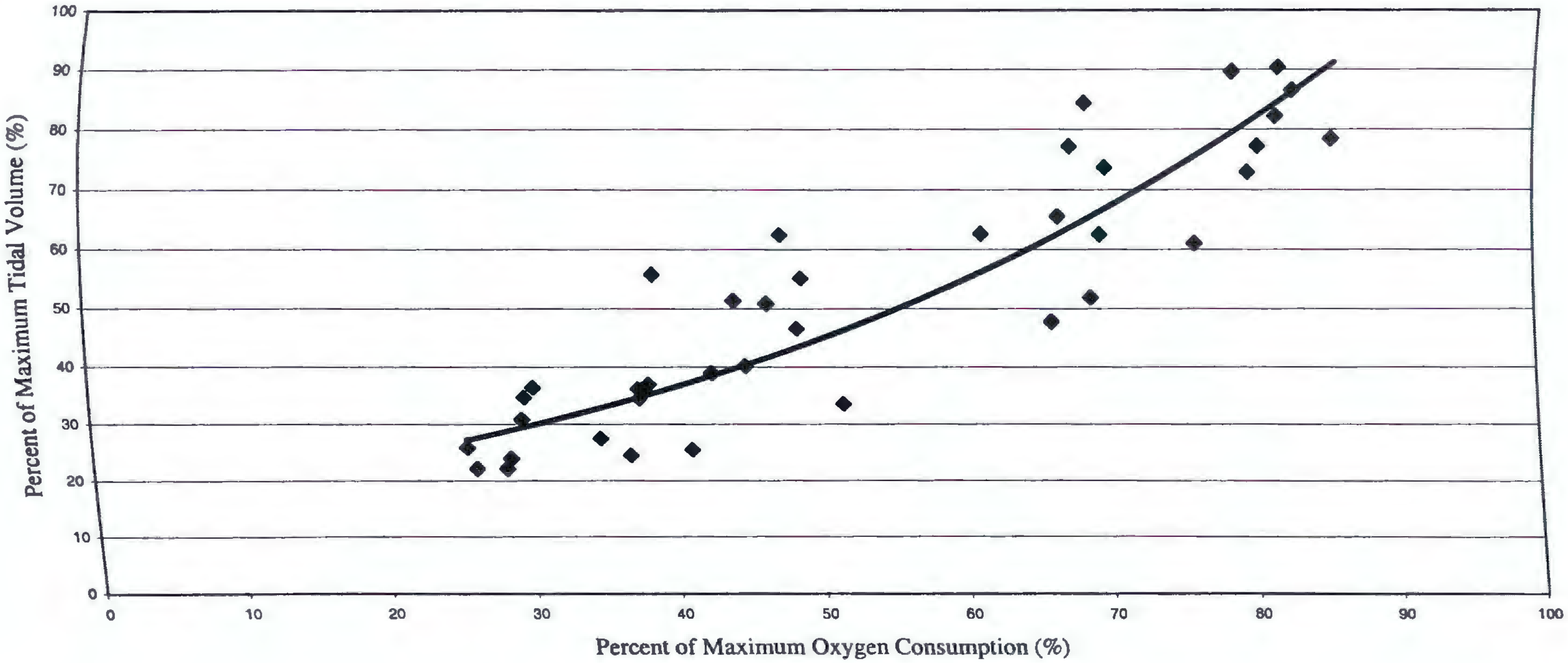


Figure 113. Exponential model fit to the pooled data from the eight subjects who completed the current study.

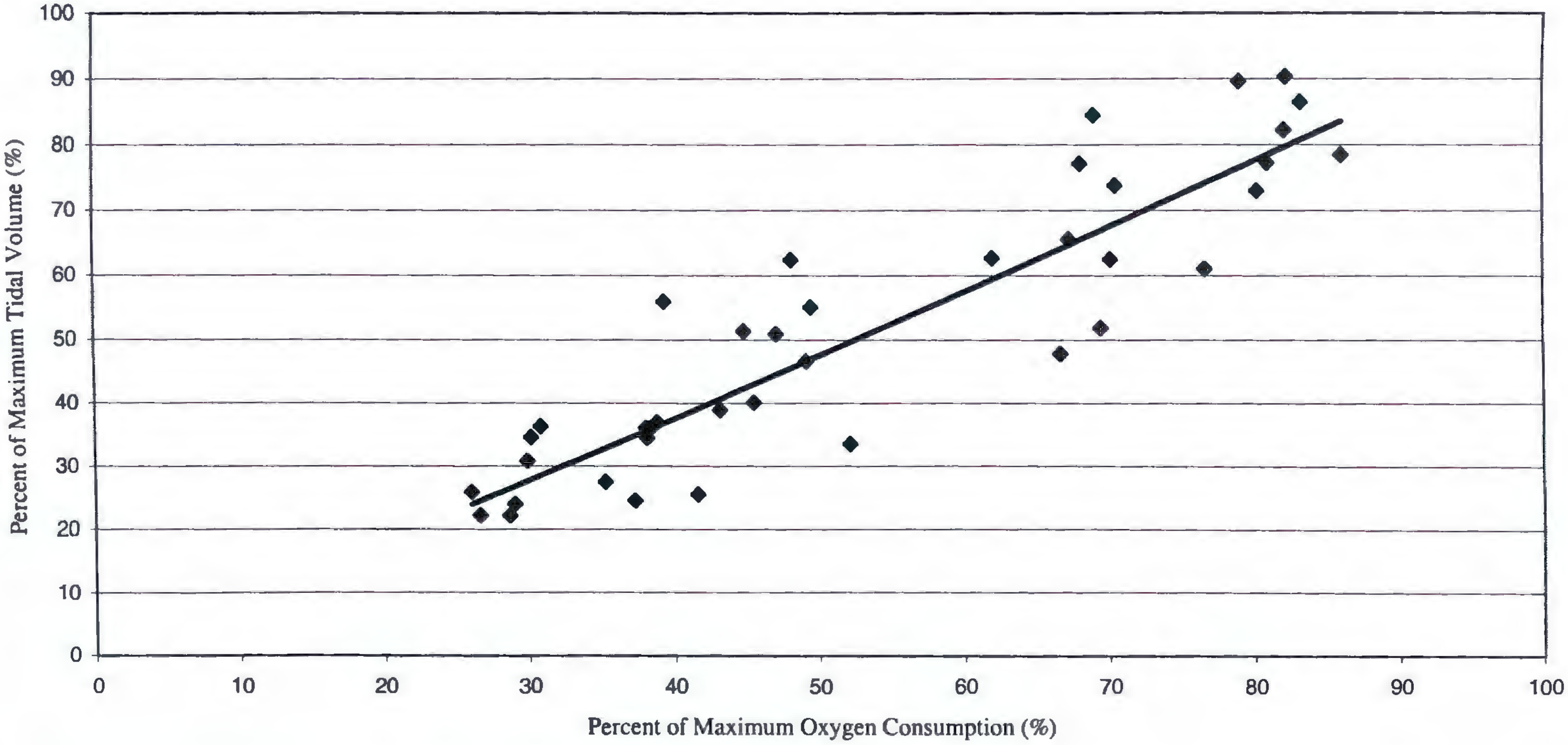


Figure 114. Power model fit to the pooled data from the eight subjects who completed the current study.

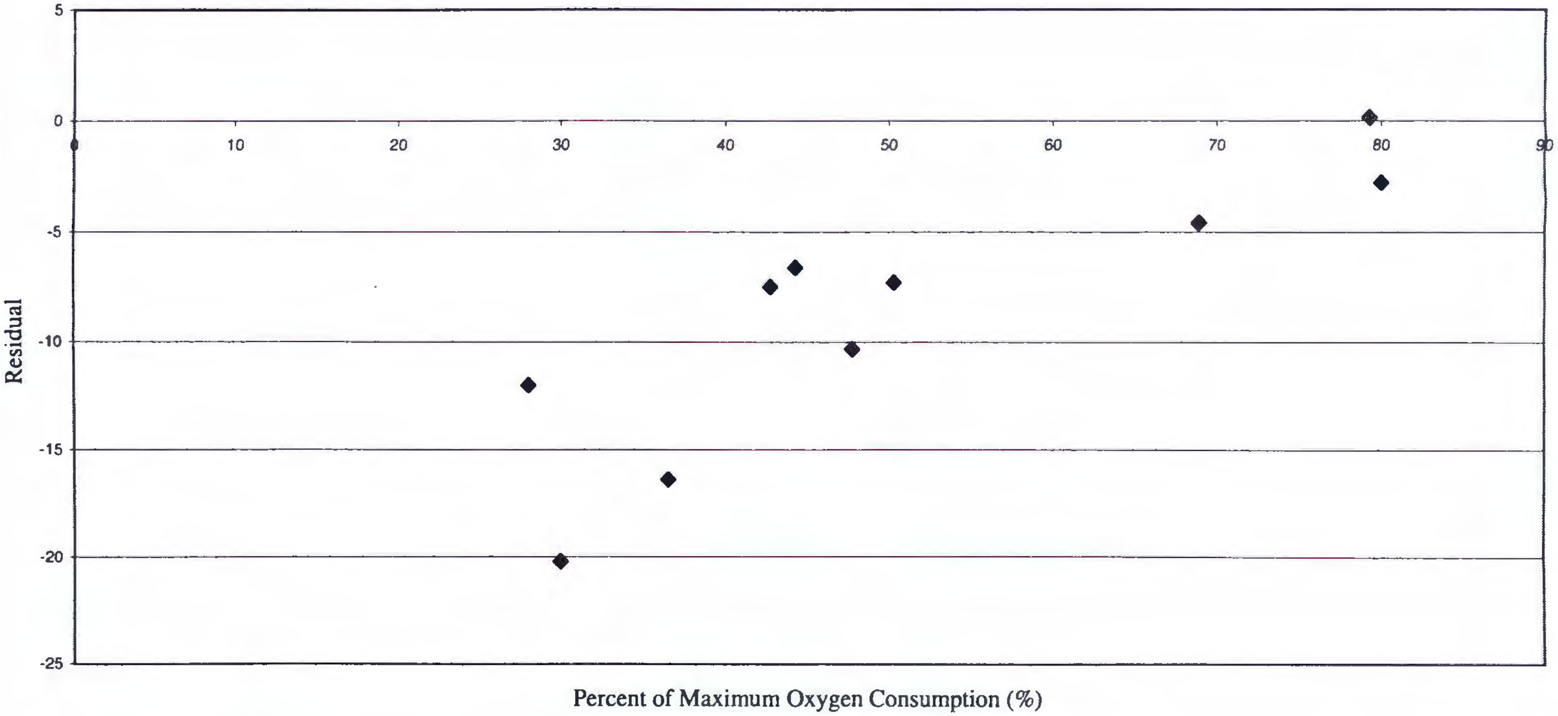


Figure 115. Residuals of percent of maximum tidal volume for two validation

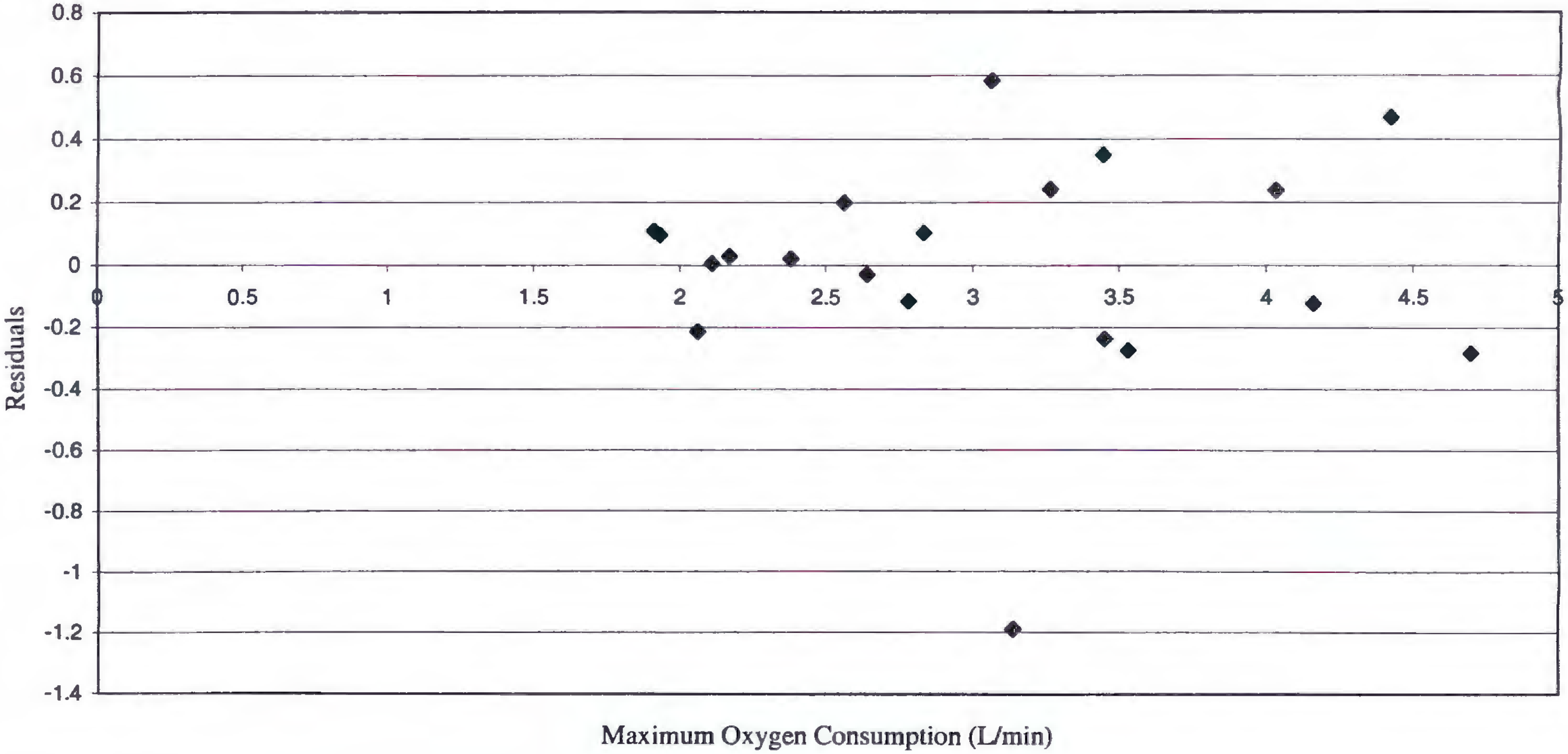


Figure 116. Residuals for VTmax as a function of VO2max.

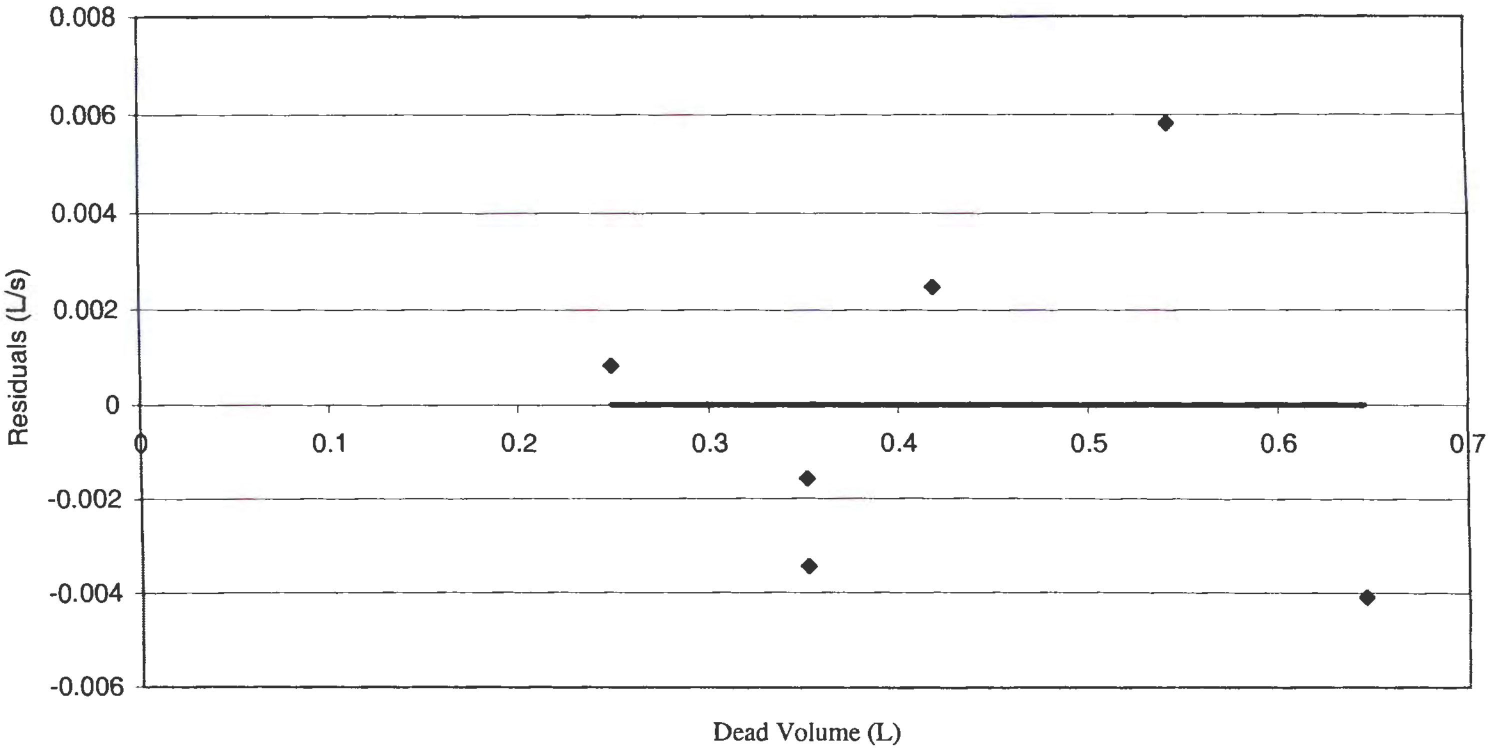


Figure 117. Residuals from the change in minute ventilation with added dead volume for resting subjects.

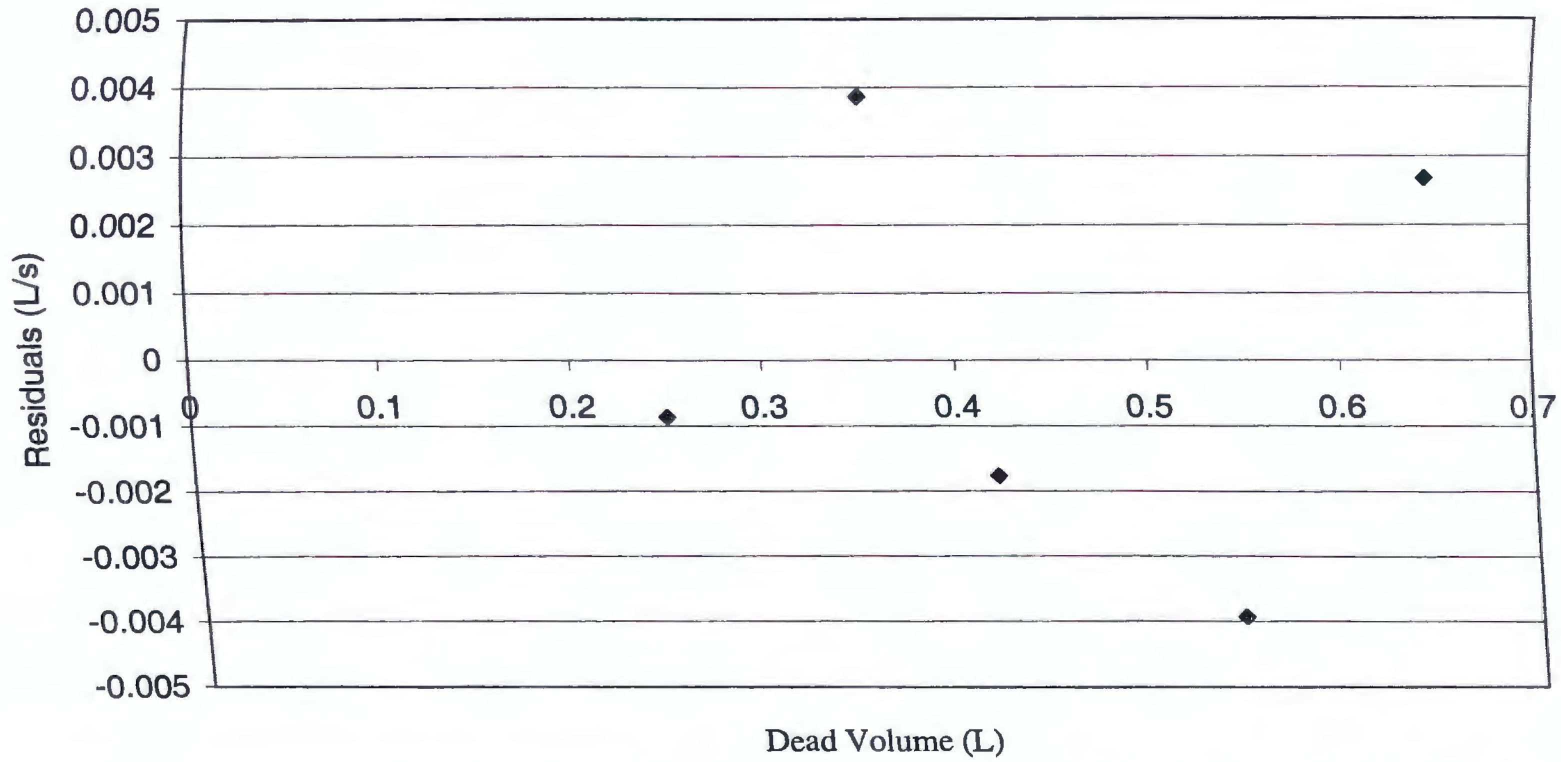


Figure 118. Residuals from the change in minute ventilation with added dead volume for lightly exercising subjects.

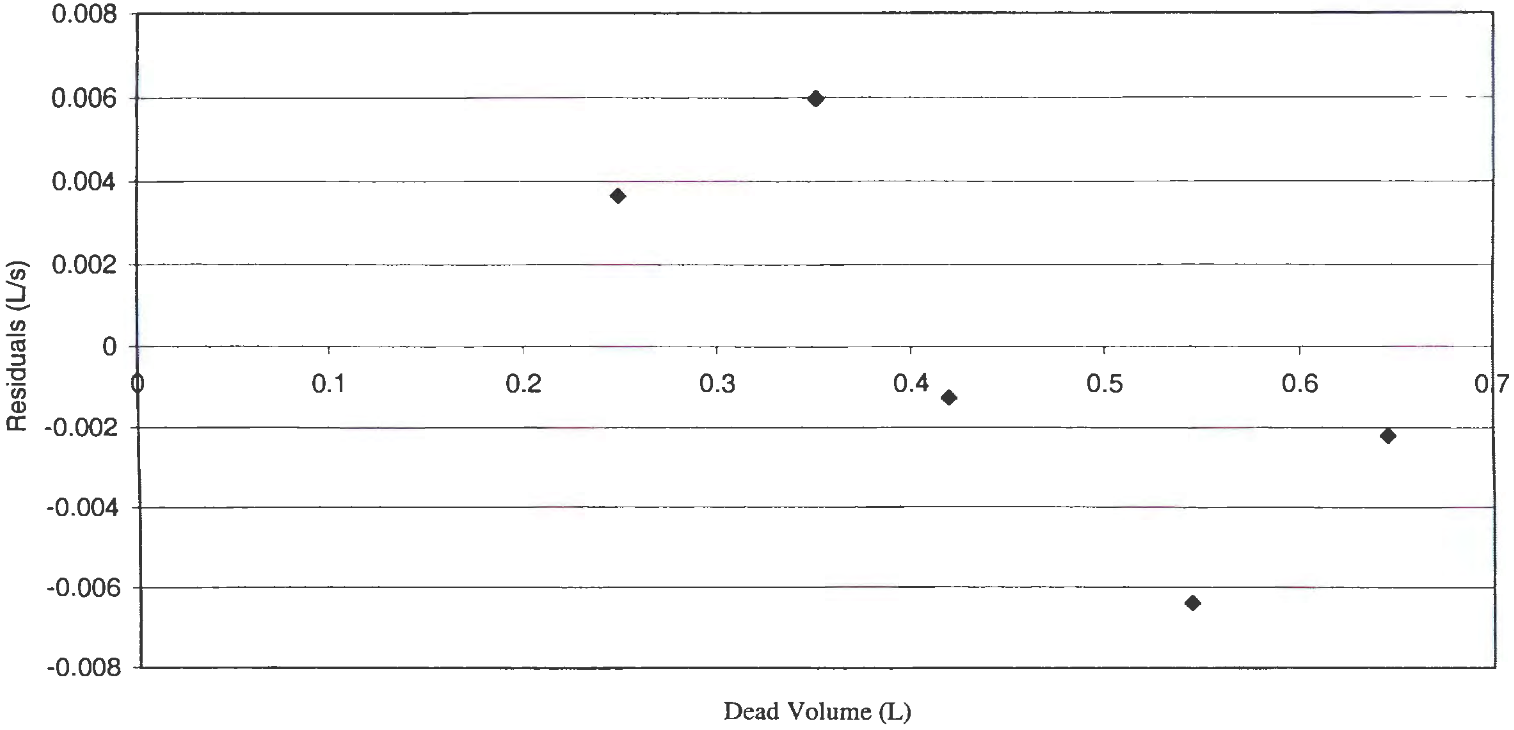


Figure 119. Residuals from the change in minute ventilation with added dead volume for subjects lightly exercising at 30% V_{O2max}.

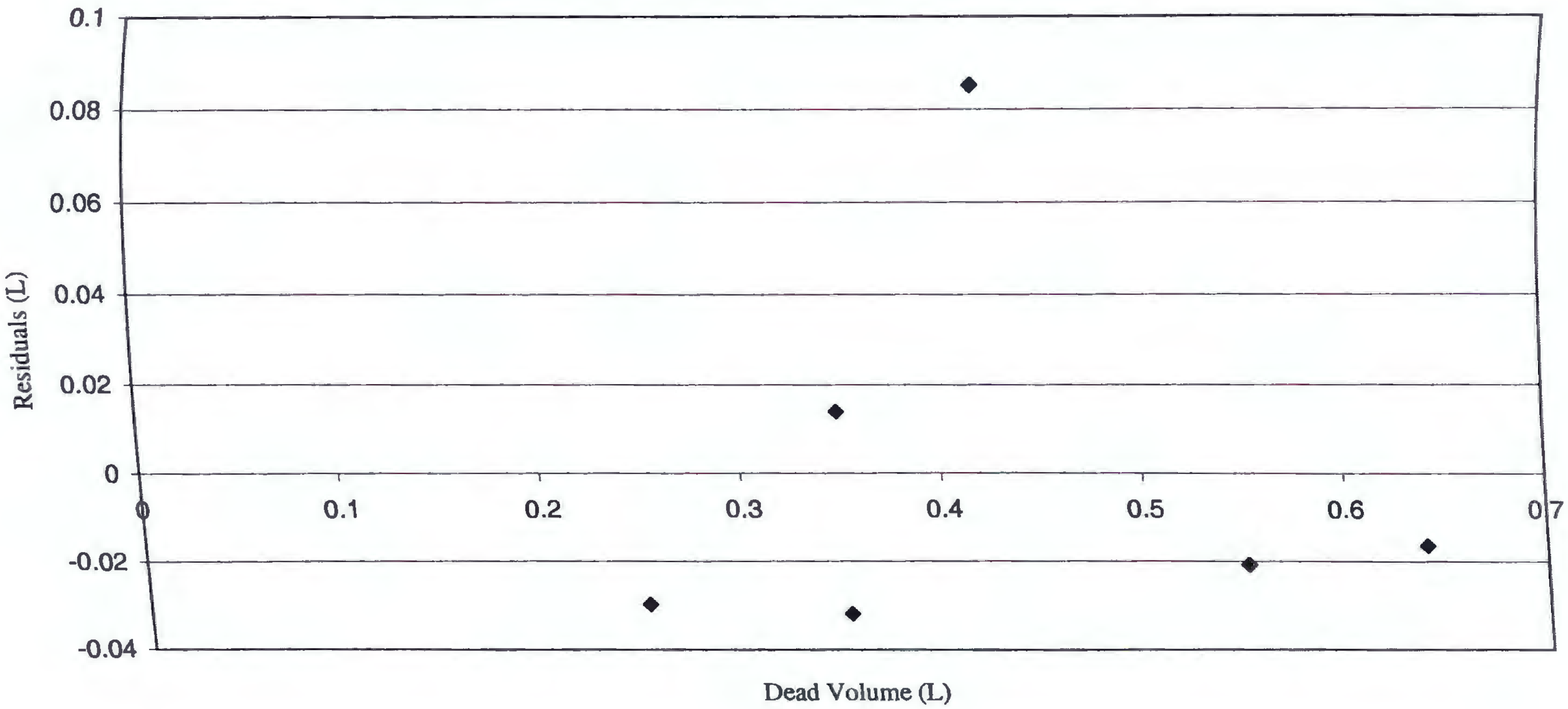


Figure 120. Residuals for the prediction of changes in tidal volume as a function of dead volume for resting subjects.

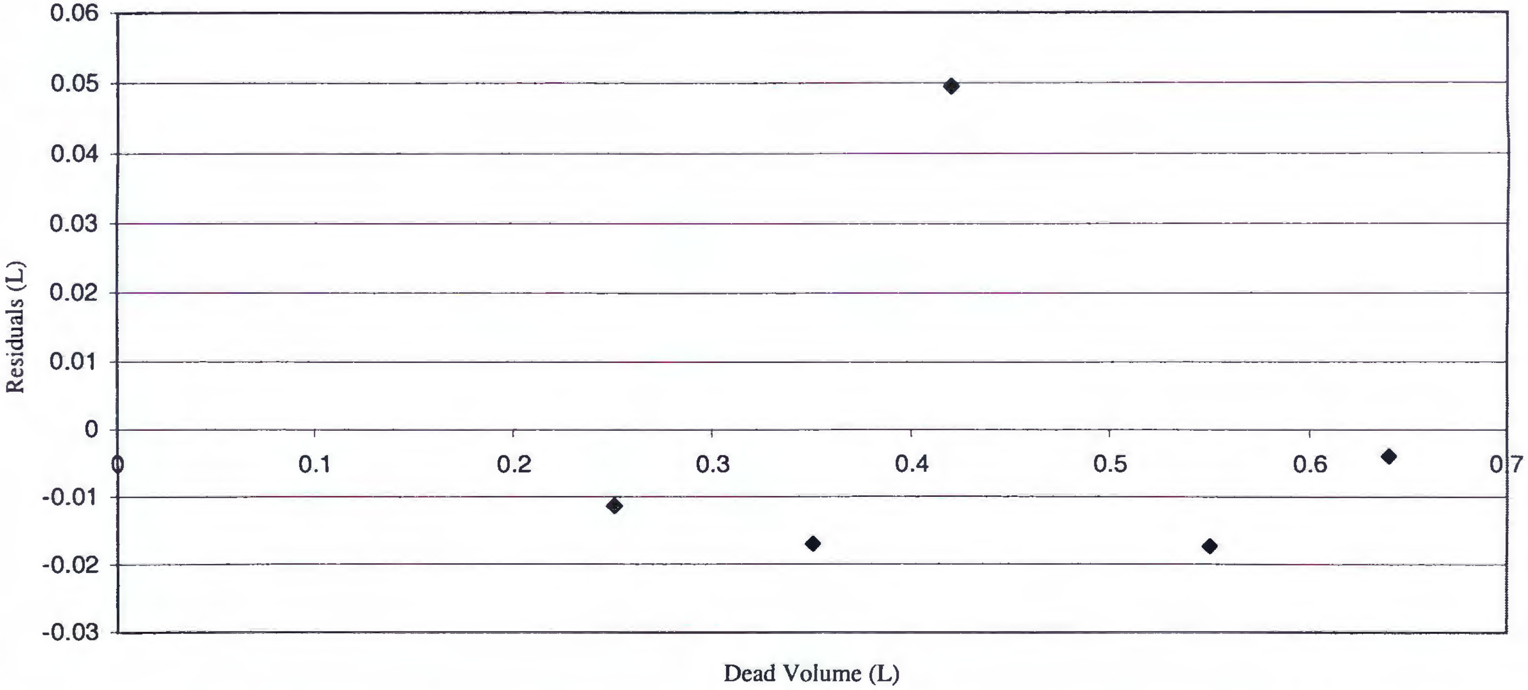


Figure 121. Residuals for the prediction of changes in tidal volume as a function of dead volume for subjects lightly exercising.

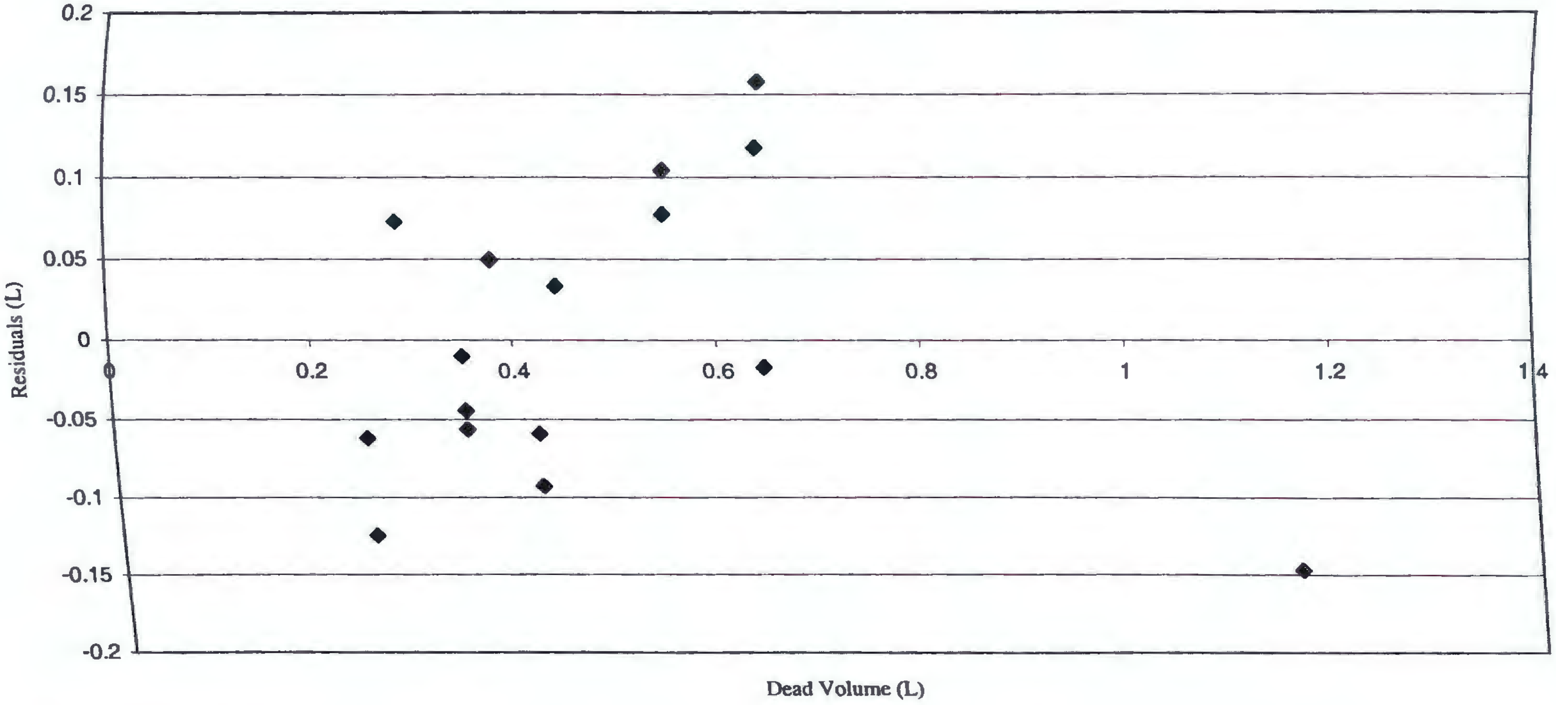


Figure 122. Residuals for the change in tidal volume as a function of dead volume and work intensity.

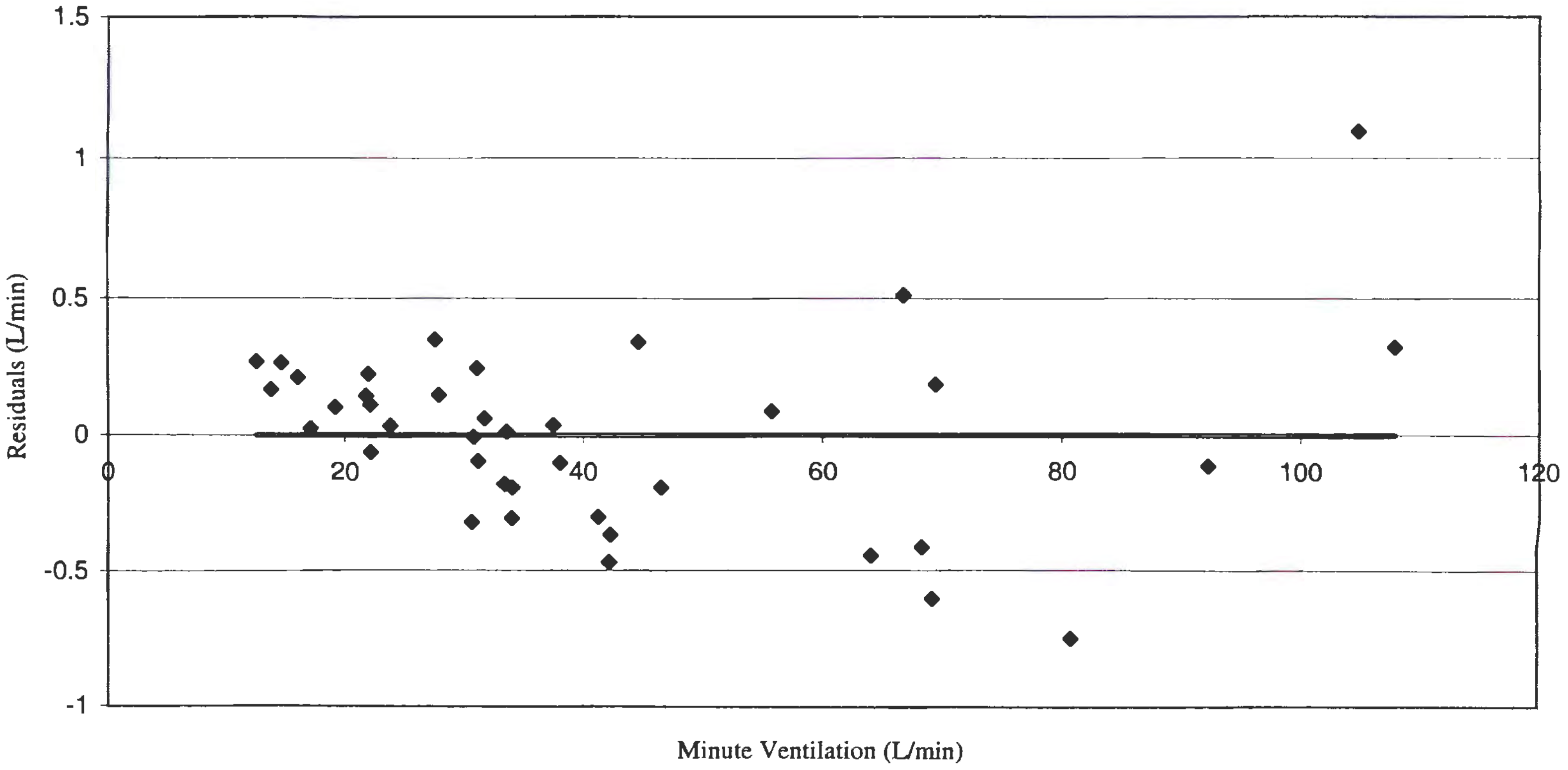


Figure 123. Residuals of oxygen consumption from regression of oxygen consumption on minute ventilation.

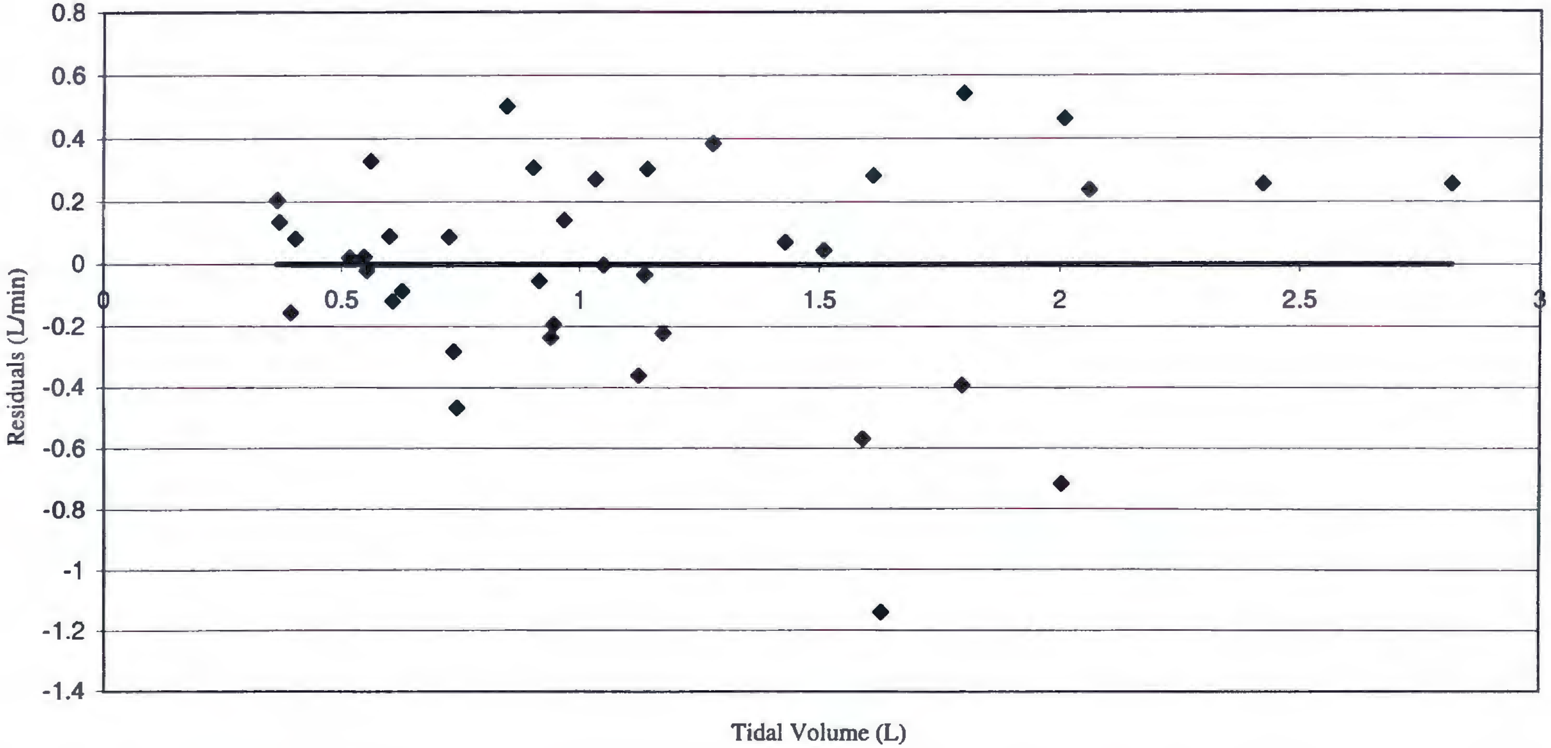


Figure 124. Residuals from linear regression of oxygen consumption on tidal volume.

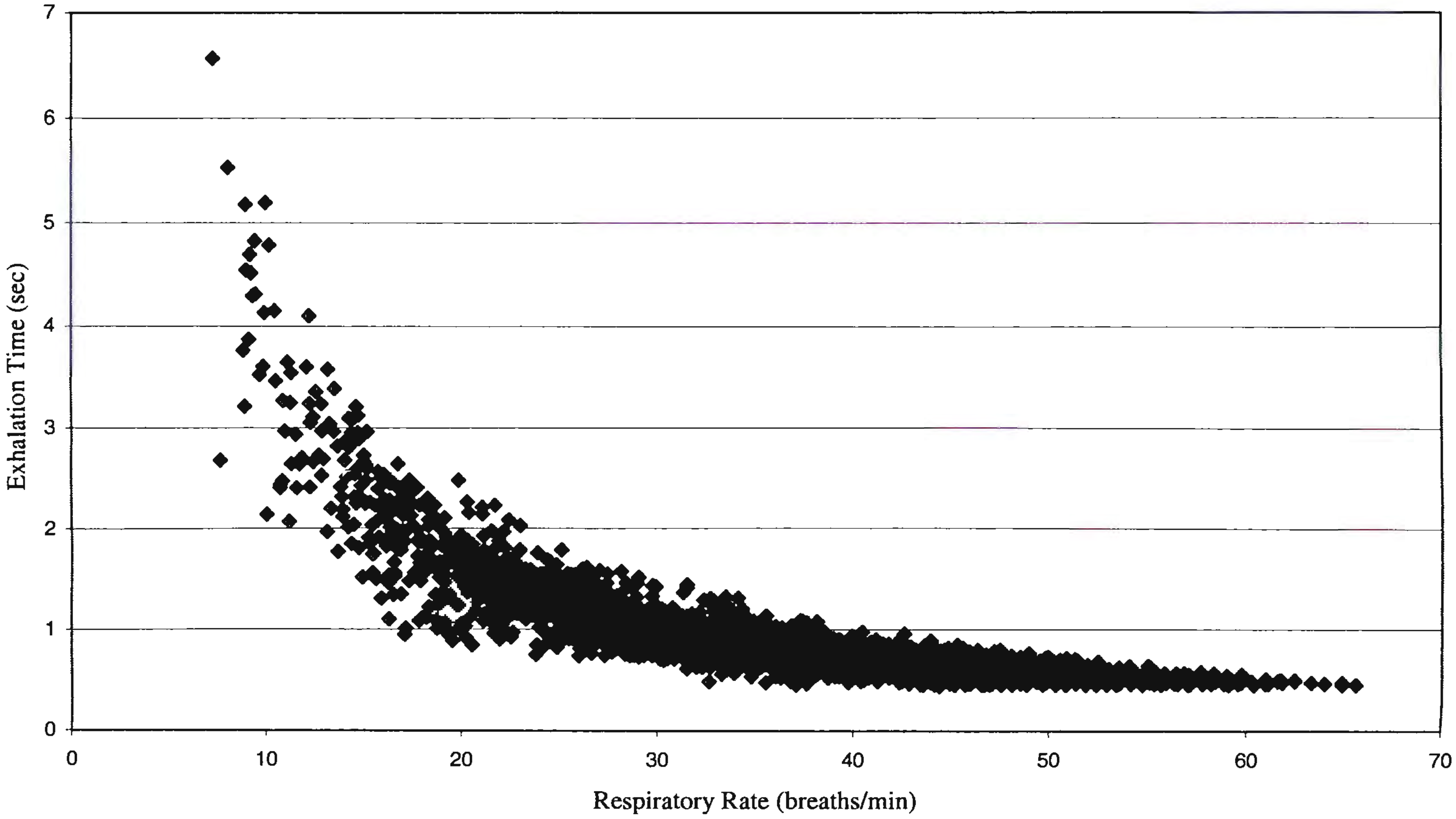


Figure 125. Exhalation time and respiratory rate calibration data.

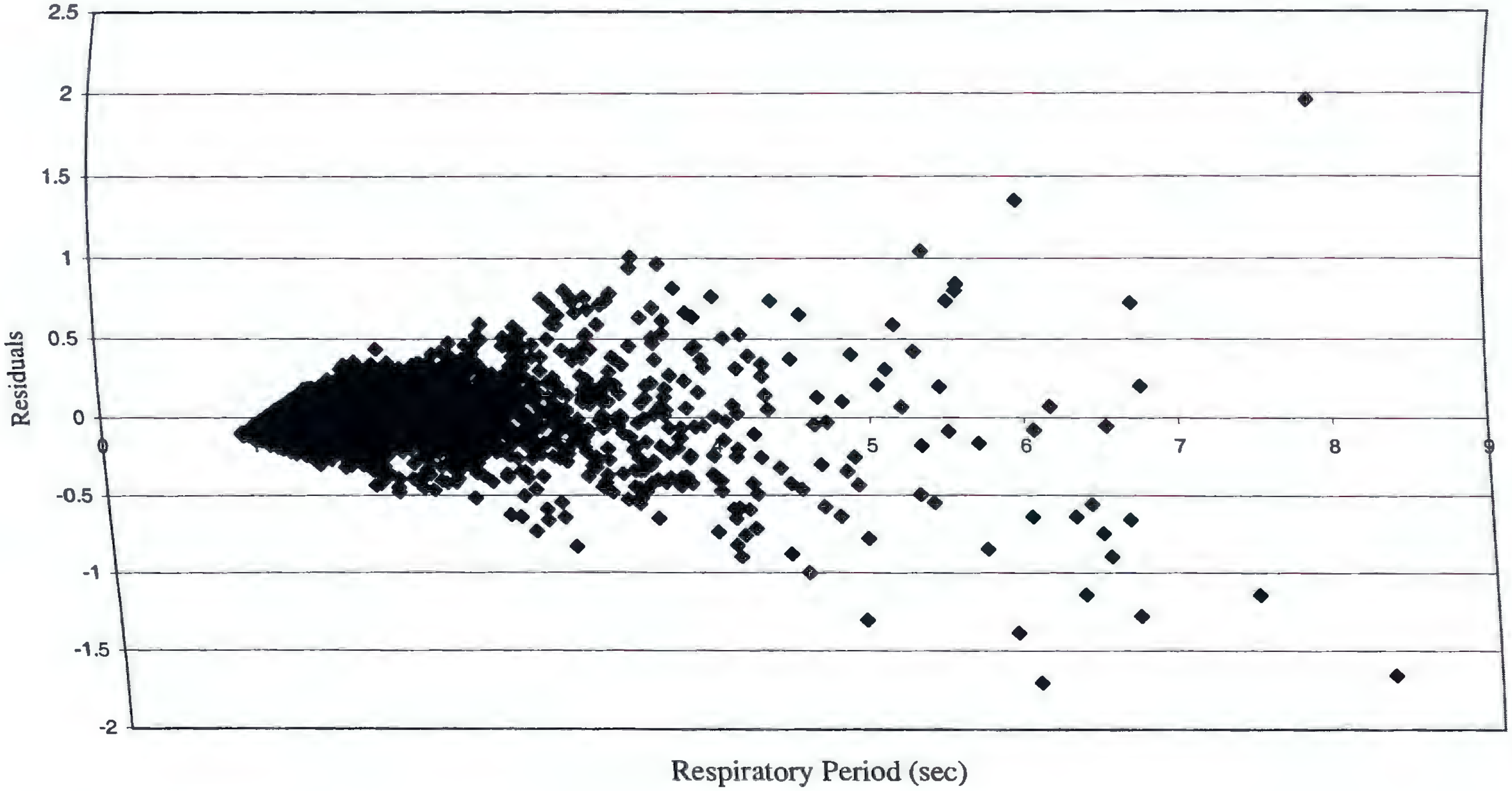


Figure 126. Exhalation time residuals from linear regression on the calibration data.

Appendix C Data

Table 20. Subject 001 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.96	2.06	47.6	1.29	1.53	16.68
0:01:07	17.87	2.13	54.26	1.26	1.8	19.57
0:01:37	17.02	2.29	55.94	1.36	2.43	26.44
0:02:08	16.7	2.4	64.54	1.65	3.05	33.11
0:02:38	16.71	2.5	62.49	1.52	2.93	31.83
0:03:09	16.74	2.52	67.06	1.68	3.11	33.8
0:03:40	16.86	2.57	70.09	1.71	3.13	34.05
0:04:10	16.94	2.54	76.12	1.65	3.34	36.26
0:04:41	17.12	2.46	79.39	1.62	3.31	36.01
0:05:11	17.29	2.42	84.62	1.73	3.36	36.57
0:05:43	17.29	2.44	89.85	1.76	3.57	38.78
0:06:13	17.3	2.47	101.4	1.78	4	43.5
0:06:44	17.36	2.44	105.2	1.88	4.08	44.34
0:07:15	17.34	2.45	110.21	1.87	4.29	46.67
0:07:46	17.43	2.38	116.33	1.79	4.42	48.07
0:08:17	17.51	2.31	118.56	1.77	4.41	47.9
0:08:47	17.37	2.43	113.77	1.75	4.4	47.85
0:09:18	17.29	2.53	65.02	1.3	2.57	27.89
0:09:50	17.07	2.68	12.66	0.28	0.53	5.76

Table 21. Subject 002 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	16.91	2.53	26.69	0.61	1.18	20.33
0:01:06	17.12	2.59	25.46	0.5	1.05	18.16
0:01:38	16.89	2.58	27.24	0.76	1.21	20.8
0:02:08	16.79	2.57	29.45	0.76	1.34	23.16
0:02:39	16.53	2.68	27.09	0.54	1.32	22.69
0:03:10	16.48	2.72	28.43	0.73	1.4	24.12
0:03:41	16.37	2.8	29.89	0.75	1.51	25.96
0:04:12	16.54	2.74	37.5	0.6	1.81	31.24
0:04:42	15.97	2.9	32.24	0.85	1.78	30.63
0:05:14	16.44	2.83	33.76	0.79	1.67	28.73
0:05:44	16.53	2.87	33.66	0.99	1.62	27.9
0:06:14	16.5	2.91	35.03	1.17	1.69	29.21
0:06:45	16.7	2.87	35.78	0.94	1.65	28.4
0:07:16	16.61	2.89	37.1	0.9	1.74	30.08
0:07:47	16.55	2.89	44.57	0.97	2.13	36.73
0:08:17	16.9	2.77	46.69	1.33	2.04	35.17
0:08:48	17.2	2.72	48.2	1.18	1.93	33.25
0:09:18	17.2	2.73	49.59	1.34	1.98	34.2
0:09:50	17.12	2.79	57.39	1.43	2.35	40.46
0:10:20	17.45	2.62	54.56	1.21	2.03	34.99
0:10:51	17.45	2.59	67.26	1.46	2.5	43.15
0:11:21	17.88	2.42	73.8	1.48	2.38	40.99
0:11:52	18.01	2.37	77.14	1.54	2.37	40.83

Table 22. Subject 023 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.25	1.98	21.58	0.36	0.89	19.02
0:01:06	16.99	2.11	25.21	0.35	1.12	23.76
0:01:37	16.58	2.3	22.44	0.56	1.1	23.43
0:02:08	16.58	2.36	24.16	0.89	1.18	25.1
0:02:38	16.65	2.39	28.13	0.69	1.35	28.64
0:03:09	16.78	2.38	27.57	0.71	1.28	27.15
0:03:40	16.72	2.41	28.14	0.78	1.32	28.11
0:04:11	16.77	2.45	28.86	0.96	1.33	28.38
0:04:41	16.91	2.44	30.18	0.75	1.34	28.53
0:05:13	16.83	2.45	33.54	0.96	1.52	32.42
0:05:43	17.09	2.39	37.69	0.84	1.59	33.93
0:06:14	17.14	2.4	44.55	1.31	1.86	39.48
0:06:44	17.39	2.33	44.93	1.55	1.74	36.94
0:07:15	17.5	2.3	45.2	1.29	1.69	35.92
0:07:46	17.49	2.31	46.04	1.32	1.73	36.74
0:08:17	17.54	2.27	49.54	1.21	1.83	38.99
0:08:47	17.73	2.16	59.36	1.65	2.06	43.92
0:09:18	18.04	2.06	63.47	1.51	1.98	42.08
0:09:49	18.13	2.01	66.87	1.63	2.02	42.91
0:10:19	18.2	1.96	65.29	1.42	1.92	40.92

Table 23. Subject 145 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.04	2.5	42.81	0.81	1.83	19.87
0:01:06	16.71	2.56	48.12	1.34	2.24	24.4
0:01:37	16.81	2.55	53.31	1.11	2.42	26.3
0:02:08	16.87	2.6	37.12	0.93	1.65	17.96
0:02:39	16.99	2.61	51.62	1.36	2.22	24.13
0:03:09	17.52	2.53	56.42	1.06	2.06	22.36
0:03:40	17.53	2.42	64.76	1.38	2.38	25.83
0:04:11	17.48	2.5	69.83	1.55	2.59	28.13
0:04:42	17.53	2.52	79.25	1.76	2.89	31.36
0:05:12	17.94	2.41	68.27	1.29	2.15	23.37
0:05:43	17.24	2.68	79.16	1.93	3.14	34.13
0:06:14	17.79	2.46	82.78	1.69	2.76	29.98
0:06:45	17.65	2.58	91.57	1.87	3.18	34.59
0:07:16	17.82	2.53	104.17	2.08	3.41	37.09
0:07:46	18.14	2.42	108.06	2.16	3.13	33.98
0:08:17	18.2	2.36	113.63	2.14	3.22	35.03
0:08:48	18.28	2.3	126.31	2.22	3.48	37.85
0:09:19	18.51	2.17	127.64	2.24	3.19	34.68
0:09:50	18.42	2.21	135.38	2.33	3.51	38.21
0:10:20	18.51	2.16	133.61	2.23	3.33	36.18

Table 24. Subject 173 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	18.07	1.92	25.65	1.28	0.8	10.67
0:01:06	17.13	2.26	26.82	1.03	1.13	15.08
0:01:38	16.16	2.42	41.6	1.39	2.25	29.96
0:02:08	16.56	2.39	44.09	1.42	2.16	28.86
0:02:38	16.67	2.49	50.86	1.7	2.41	32.15
0:03:10	16.86	2.51	50.92	1.76	2.28	30.45
0:03:40	16.72	2.62	53.84	1.86	2.5	33.27
0:04:11	16.83	2.64	55.72	1.8	2.5	33.39
0:04:41	16.94	2.6	57.72	1.86	2.52	33.62
0:05:12	17.06	2.6	60.3	1.88	2.54	33.85
0:05:43	17.07	2.64	63.75	1.99	2.67	35.62
0:06:14	17.27	2.73	68.35	2.14	2.68	35.73
0:06:45	17.31	2.78	72.03	2.18	2.77	36.97
0:07:16	17.37	2.76	71.08	1.97	2.69	35.84
0:07:48	17.41	2.73	74.46	2.19	2.79	37.15
0:08:18	17.43	2.71	77.5	2.35	2.88	38.43
0:08:48	17.49	2.69	79.39	2.34	2.9	38.64
0:09:20	17.45	2.72	80.36	2.36	2.97	39.56
0:09:50	17.48	2.71	82.79	2.44	3.03	40.35
0:10:21	17.56	2.7	84.39	2.34	3.01	40.08
0:10:52	17.65	2.63	88.96	2.28	3.07	40.99
0:11:22	17.79	2.56	95.99	2.29	3.17	42.29

Table 25. Subject 214 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	18.65	2	11.79	0.84	0.28	3.62
0:01:06	17.88	2.41	12.29	0.82	0.4	5.15
0:01:37	17.52	2.54	14.18	0.75	0.52	6.72
0:02:08	17.36	2.61	16.85	0.84	0.65	8.39
0:02:39	17.26	2.74	32.6	0.84	1.28	16.6
0:03:09	16.16	3.38	36.29	1.13	1.87	24.25
0:03:40	16.18	3.42	53.42	1.78	2.73	35.44
0:04:11	16.2	3.62	52.95	2.21	2.66	34.55
0:04:42	15.74	3.9	56.06	2.8	3.1	40.27
0:05:13	16	3.86	63.63	2.65	3.32	43.06
0:05:44	16.15	3.82	67.3	3.06	3.39	43.97
0:06:14	16.35	3.71	66.53	2.15	3.2	41.53
0:06:44	16.16	3.79	71.48	2.75	3.6	46.65
0:07:15	16.23	3.71	72.54	2.9	3.6	46.75
0:07:46	16.12	3.8	73.47	2.62	3.74	48.5
0:08:17	16.12	3.86	75.34	2.9	3.82	49.53
0:08:48	16.15	3.89	77.54	2.77	3.9	50.53
0:09:18	16.38	3.77	76.46	2.94	3.64	47.23
0:09:49	16.26	3.84	79.32	2.64	3.89	50.44
0:10:20	16.48	3.76	96.9	3.13	4.5	58.37
0:10:51	16.62	3.79	111.61	2.79	4.97	64.5
0:11:22	16.97	3.63	116.83	3.16	4.74	61.52
0:11:53	17.14	3.53	117.12	2.93	4.53	58.72
0:12:23	17.09	3.53	123.15	2.8	4.83	62.67
0:12:54	17.28	3.4	123.26	2.8	4.59	59.53
0:13:25	17.39	3.34	132.32	2.5	4.77	61.83
0:13:55	17.51	3.21	123.39	2.37	4.3	55.72
0:14:26	17.57	3.18	19.3	0.41	0.66	8.54

Table 26. Subject 221 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:36	15.35	3.13	35.06	0.95	2.19	29.17
0:01:07	15.5	3.12	39.81	1	2.41	32.14
0:01:37	15.28	3.31	46.95	1.47	2.95	39.32
0:02:08	15.68	3.37	53.35	1.44	3.07	40.94
0:02:38	16.01	3.27	51.33	1.71	2.75	36.72
0:03:09	15.99	3.33	58.58	1.15	3.15	41.98
0:03:40	15.77	3.4	60.49	1.14	3.41	45.42
0:04:12	16.19	3.32	70.09	1.75	3.59	47.83
0:04:42	16.42	3.22	76.39	2.06	3.72	49.54
0:05:13	16.83	3.08	73.94	1.95	3.23	43.11
0:05:44	16.71	3.11	78.38	2.12	3.55	47.29
0:06:14	16.64	3.1	72.51	1.65	3.34	44.59
0:06:45	16.63	3.08	84.36	2.16	3.91	52.14
0:07:16	16.99	2.94	92.87	1.98	3.91	52.14
0:07:47	16.91	2.98	99.14	2.42	4.26	56.81
0:08:17	16.86	3.02	98.28	2.05	4.28	57.07
0:08:49	17.11	2.95	102.85	2.24	4.17	55.67
0:09:19	17.12	2.91	103.03	1.54	4.17	55.64
0:09:50	16.43	3.21	114.77	2.67	5.56	74.2
0:10:21	17.32	2.85	115.57	2.46	4.42	58.94
0:10:51	17.23	2.85	116.62	2.12	4.58	61.1
0:11:22	17.33	2.77	120.39	2.74	4.61	61.45
0:11:53	17.43	2.69	126.5	2.69	4.7	62.72
0:12:23	17.47	2.64	123.06	2.56	4.54	60.53

Table 27. Subject 224 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	16.67	2.72	36.4	0.93	1.7	28.35
0:01:06	16.87	2.49	37.41	0.85	1.68	28
0:01:37	16.55	2.49	41.08	0.84	2.01	33.44
0:02:08	16.33	2.53	43.72	0.93	2.26	37.61
0:02:38	16.41	2.58	48.18	1.12	2.43	40.53
0:03:10	16.63	2.61	50.64	1.08	2.41	40.12
0:03:40	16.77	2.59	47.59	0.95	2.18	36.36
0:04:11	16.37	2.71	52.16	0.84	2.64	43.94
0:04:41	16.1	2.82	57.09	1.27	3.07	51.12
0:05:12	16.68	2.68	57.55	1.22	2.69	44.86
0:05:43	16.85	2.6	60.33	1.28	2.7	45.06
0:06:14	16.9	2.57	60.68	1.21	2.68	44.72
0:06:44	16.91	2.57	57.1	0.98	2.52	42.02
0:07:15	16.7	2.64	62.71	1.28	2.92	48.71
0:07:46	16.85	2.59	61.62	0.98	2.76	46.01
0:08:17	16.56	2.69	70.76	1.31	3.42	56.93
0:08:47	16.8	2.66	76.25	1.11	3.45	57.5
0:09:18	16.97	2.61	75.96	1.43	3.29	54.77
0:09:50	17.1	2.56	77.32	1.52	3.23	53.75
0:10:20	17.14	2.53	79.69	1.48	3.3	54.93

Table 28. Subject 230 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	16.72	2.29	21.34	0.51	1.01	15.89
0:01:06	16.25	2.43	29.09	0.57	1.54	24.22
0:01:37	15.64	2.62	26.56	0.63	1.59	25.11
0:02:08	15.03	2.68	40.59	0.88	2.74	43.19
0:02:39	15.05	2.77	39.83	1.14	2.67	42.06
0:03:10	15.65	2.87	40.9	1.05	2.42	38.13
0:03:40	15.89	3.04	48.27	1.18	2.69	42.38
0:04:11	16.43	2.89	47.73	0.92	2.35	37.06
0:04:42	16.6	2.82	51.08	1.19	2.42	38.13
0:05:12	16.76	2.84	53.98	1	2.44	38.48
0:05:43	16.92	2.77	60.35	1.28	2.63	41.35
0:06:14	16.99	2.79	65.08	1.45	2.77	43.58
0:06:44	17.18	2.7	64.57	1.5	2.61	41.06
0:07:15	17.1	2.77	72.75	1.62	2.99	47.14
0:07:46	17.48	2.58	69.5	1.29	2.57	40.42
0:08:17	17.52	2.49	76.4	1.56	2.8	44.08
0:08:48	17.43	2.49	69.63	1.42	2.63	41.43
0:09:19	17.22	2.58	80.55	1.58	3.23	50.89

Table 29. Subject 231 V_{O2max} test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.29	2.16	21.86	0.5	0.88	14.29
0:01:06	16.54	2.41	28.35	0.77	1.4	22.61
0:01:37	16.02	2.44	29.92	0.75	1.67	27.03
0:02:08	15.93	2.52	35.73	0.94	2.02	32.76
0:02:39	16.13	2.56	34.79	0.89	1.88	30.46
0:03:10	16.01	2.68	39.76	1.17	2.19	35.54
0:03:40	16.23	2.72	37.98	0.88	1.99	32.2
0:04:11	16.28	2.7	40.49	1.19	2.09	33.92
0:04:42	16.3	2.7	38.93	0.97	2	32.49
0:05:12	16.39	2.7	42.51	1.04	2.14	34.67
0:05:44	16.44	2.69	45.78	1.2	2.28	36.91
0:06:14	16.49	2.72	49.17	1.26	2.41	39.02
0:06:46	16.55	2.72	48.58	1.35	2.35	38.06
0:07:16	16.66	2.7	52.77	1.43	2.48	40.18
0:07:46	16.86	2.62	51.24	1.11	2.29	37.11
0:08:17	16.75	2.6	54.61	1.37	2.52	40.8
0:08:48	16.85	2.58	58.81	1.51	2.64	42.73
0:09:18	16.87	2.59	54.81	1.25	2.44	39.57
0:09:49	17.07	2.55	57.28	1.36	2.42	39.19
0:10:20	17.01	2.56	54.18	1.08	2.32	37.6
0:10:51	16.87	2.61	63.6	1.41	2.83	45.89
0:11:22	17.33	2.44	61.48	1.4	2.41	39.01
0:11:52	17.3	2.44	64.47	1.43	2.55	41.36
0:12:23	17.31	2.43	65.04	1.41	2.56	41.57
0:12:54	17.42	2.43	67.34	1.37	2.56	41.52
0:13:25	17.52	2.39	66.21	1.38	2.44	39.56

Table 30. Subject 001 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	16.22	2.53	26.99	1.04	1.43	15.54
0:01:06	15.91	2.62	25.98	0.76	1.47	15.97
0:01:37	15.58	2.73	30.33	0.72	1.83	19.94
0:02:08	16.18	2.63	29.86	0.85	1.59	17.28
0:02:39	16.38	2.61	29	0.97	1.47	15.98
0:03:10	16.49	2.59	31.77	1.13	1.57	17.06
0:03:40	16.56	2.58	28.16	0.88	1.37	14.85
0:04:11	16.4	2.64	30.12	0.91	1.52	16.49
0:04:42	16.18	2.68	33.18	1.11	1.76	19.15
0:05:13	16.33	2.63	33.13	0.95	1.7	18.46
0:05:44	16.19	2.7	33.67	1.09	1.78	19.35
0:06:15	16.31	2.64	36.33	1.14	1.87	20.36
0:06:45	16.32	2.67	38.52	1.38	1.97	21.46
0:07:16	16.45	2.7	39.24	1.15	1.94	21.12
0:07:47	16.4	2.71	41.79	0.97	2.1	22.78
0:08:17	16.34	2.68	39.48	1.27	2.02	21.93
0:08:48	16.06	2.77	42.21	1.28	2.29	24.92
0:09:19	16.11	2.78	45.14	1.22	2.43	26.37
0:09:50	16.31	2.72	49.73	1.18	2.55	27.72
0:10:21	16.54	2.64	57.03	1.5	2.77	30.1
0:10:51	16.68	2.58	58.23	1.53	2.74	29.77
0:11:22	16.72	2.61	59.41	1.49	2.75	29.94
0:11:53	16.69	2.69	61.25	1.53	2.85	31.03
0:12:23	16.69	2.7	57.54	1.6	2.68	29.1
0:12:54	16.5	2.78	60.45	1.41	2.94	32.01
0:13:25	16.62	2.74	62.68	1.53	2.97	32.25
0:13:56	16.49	2.83	65.68	1.73	3.21	34.84
0:14:27	16.7	2.76	67.22	1.68	3.11	33.85
0:14:57	16.72	2.72	68.24	1.66	3.14	34.16
0:15:28	16.88	2.83	76.71	1.78	3.36	36.48
0:15:59	17.08	2.77	82.52	1.65	3.42	37.18
0:16:30	17.2	2.72	88.16	1.73	3.53	38.41
0:17:01	17.15	2.73	94.64	1.79	3.85	41.82
0:17:32	17.29	2.66	94.11	1.36	3.67	39.91
0:18:02	16.94	2.81	102.5	1.8	4.41	47.98
0:18:33	17.29	2.72	109	1.95	4.25	46.16
0:19:04	17.32	2.72	104.7	1.87	4.04	43.9
0:19:34	17.07	2.83	107.9	1.83	4.47	48.57
0:20:05	17.39	2.65	45	0.68	1.7	18.5
0:20:36	17.22	2.75	9.56	0.12	0.38	4.13

Table 31. Subject 002 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:36	17.65	1.85	17.28	0.38	0.63	10.91
0:01:07	16.92	2.3	16.79	0.31	0.75	12.96
0:01:37	16.39	2.48	17.88	0.66	0.91	15.71
0:02:08	16.04	2.66	16.57	0.35	0.91	15.67
0:02:39	15.86	2.71	17.24	0.39	0.98	16.94
0:03:10	15.68	2.79	16.63	0.45	0.98	16.93
0:03:41	15.77	2.81	17.46	0.34	1.01	17.43
0:04:11	15.89	2.79	18.54	0.6	1.05	18.03
0:04:42	16.15	2.66	19.45	0.63	1.04	17.94
0:05:13	16.37	2.61	18.55	0.48	0.94	16.28
0:05:43	16.37	2.64	19.78	0.76	1	17.29
0:06:14	16.3	2.63	20.7	0.67	1.07	18.44
0:06:45	16.49	2.52	20.56	0.64	1.02	17.56
0:07:16	16.34	2.63	22.39	0.72	1.15	19.76
0:07:47	16.52	2.6	23.12	0.86	1.13	19.52
0:08:18	16.69	2.52	21.31	0.56	1	17.29
0:08:49	16.71	2.61	23.84	0.61	1.11	19.11
0:09:19	16.98	2.53	23.37	0.51	1.01	17.48
0:09:50	16.75	2.54	23.12	0.66	1.07	18.45
0:10:21	16.68	2.51	19.23	0.62	0.91	15.65
0:10:51	16.43	2.57	22.05	0.4	1.11	19.1
0:11:22	16.37	2.57	19.75	0.76	1.01	17.35
0:11:53	16.32	2.64	22.23	0.58	1.14	19.68
0:12:24	16.31	2.66	22.55	0.56	1.16	20.02
0:12:55	16.44	2.67	20.28	0.48	1.01	17.39
0:13:25	16.44	2.66	18.26	0.79	0.91	15.67
0:13:56	16.17	2.74	21.15	0.56	1.12	19.35
0:14:27	16.13	2.76	18.81	0.52	1.01	17.35
0:14:58	16.23	2.76	22.19	0.89	1.16	19.95
0:15:28	16.53	2.66	23.66	0.58	1.15	19.86
0:15:59	16.66	2.58	22.65	0.76	1.07	18.44
0:16:30	16.76	2.58	21.86	0.64	1.01	17.34
0:17:01	16.54	2.65	22.84	0.63	1.11	19.15
0:17:32	16.69	2.62	19.93	0.37	0.93	16.07
0:18:03	16.48	2.56	29.53	0.66	1.46	25.23
0:18:33	16.44	2.58	26.25	0.73	1.31	22.65
0:19:05	16.58	2.61	25.82	0.68	1.24	21.45
0:19:35	16.44	2.65	30.41	0.53	1.52	26.17
0:20:06	16.28	2.67	32.96	0.87	1.71	29.48
0:20:36	16.43	2.69	34.52	1.02	1.72	29.65
0:21:07	16.44	2.72	35.54	0.87	1.76	30.4

Table 31. Subject 002 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:21:38	16.57	2.69	40.3	1.09	1.94	33.4
0:22:09	16.84	2.6	36.65	0.99	1.65	28.43
0:22:40	16.71	2.6	36.88	0.7	1.72	29.58
0:23:10	16.37	2.67	37.68	0.88	1.91	32.89
0:23:41	16.44	2.66	38.56	1.04	1.92	33.1
0:24:12	16.64	2.58	37.7	0.99	1.79	30.88
0:24:43	16.8	2.51	36.64	0.85	1.67	28.85
0:25:13	16.65	2.56	36.65	0.96	1.74	29.97
0:25:44	16.48	2.58	31.56	0.79	1.57	26.99
0:26:15	16.37	2.64	31.47	0.75	1.6	27.58
0:26:46	16.24	2.67	30.65	0.67	1.6	27.66
0:27:17	16.16	2.73	28.78	0.6	1.53	26.38
0:27:48	16.72	2.46	9.92	0.16	0.46	8.01
0:28:19	16.94	2.31	9.75	0.14	0.43	7.48
0:00:36	20.08	0.43	19.05	0.73	0.18	3.17
0:01:06	17.41	1.88	16.2	0.54	0.64	11.06
0:01:37	16.91	2.25	16.58	0.79	0.75	12.85
0:02:08	16.23	2.45	18.74	0.94	0.99	17.15
0:02:38	16.07	2.5	16.91	0.48	0.93	16.03
0:03:10	16.06	2.48	15.86	0.41	0.87	15.07
0:03:40	15.97	2.51	15.51	0.4	0.87	15.04
0:04:11	15.91	2.54	15.53	0.52	0.88	15.22
0:04:42	16.12	2.5	15.23	0.69	0.83	14.26
0:05:12	16.18	2.48	13.34	0.78	0.71	12.33
0:05:43	16.22	2.5	14.03	0.56	0.74	12.84
0:06:14	16.15	2.53	13.81	0.34	0.74	12.81
0:06:44	16.17	2.53	14.05	0.56	0.75	12.98

Table 32. Subject 023 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.44	2.04	12.97	0.38	0.5	10.72
0:01:06	17.08	2.22	13.55	0.35	0.58	12.37
0:01:37	16.89	2.3	13.14	0.36	0.59	12.59
0:02:07	16.64	2.35	14.51	0.37	0.7	14.85
0:02:38	16.65	2.33	15.59	0.28	0.75	15.93
0:03:09	16.61	2.36	12.96	0.29	0.63	13.37
0:03:40	16.52	2.38	15.1	0.41	0.75	15.93
0:04:11	16.6	2.35	14.67	0.37	0.71	15.19
0:04:42	16.72	2.34	14.91	0.44	0.7	14.95
0:05:13	16.79	2.33	15.24	0.42	0.7	14.99
0:05:44	16.72	2.26	15.67	0.41	0.74	15.8
0:06:15	16.78	2.28	13.2	0.29	0.61	13.07
0:06:45	16.52	2.41	13.92	0.31	0.69	14.66
0:07:16	16.11	2.59	14.68	0.37	0.8	16.93
0:07:47	16.31	2.47	17.19	0.45	0.89	19
0:08:17	16.74	2.29	15.92	0.36	0.75	15.91
0:08:48	16.69	2.29	16.02	0.44	0.76	16.25
0:09:19	16.58	2.32	16.06	0.41	0.79	16.72
0:09:49	16.76	2.28	16.37	0.41	0.77	16.31
0:10:20	16.86	2.27	16.43	0.42	0.75	15.93
0:10:51	16.82	2.29	18.79	0.65	0.86	18.39
0:11:22	16.95	2.24	18.1	0.52	0.8	17.11
0:11:53	17.07	2.24	16.17	0.38	0.7	14.8
0:12:24	17.01	2.27	18.29	0.47	0.8	16.99
0:12:55	16.97	2.25	17.79	0.41	0.79	16.72
0:13:25	16.85	2.27	18.54	0.34	0.85	18.01
0:13:56	16.91	2.24	17.38	0.39	0.78	16.65
0:14:26	16.74	2.32	17.89	0.47	0.84	17.86
0:14:57	16.76	2.3	19.43	0.45	0.91	19.33
0:15:28	16.76	2.28	19.8	0.5	0.93	19.72
0:16:00	16.73	2.35	19.16	0.43	0.9	19.14
0:16:30	16.63	2.36	18.99	0.51	0.92	19.49
0:17:00	16.55	2.35	20.79	0.53	1.03	21.82
0:17:31	16.44	2.38	21.69	0.53	1.1	23.33
0:18:02	16.48	2.39	22.31	0.47	1.11	23.72
0:18:32	16.69	2.36	21.72	0.57	1.03	21.95
0:19:03	16.72	2.39	24.77	0.67	1.16	24.75
0:19:34	16.76	2.36	21.85	0.55	1.02	21.64
0:20:05	16.7	2.36	22.82	0.56	1.08	23
0:20:36	16.67	2.37	23.13	0.46	1.1	23.49
0:21:07	16.44	2.44	25.1	0.47	1.27	26.94
0:21:37	16.57	2.38	26.04	0.61	1.28	27.13
0:22:09	16.8	2.36	28.15	0.83	1.3	27.62
0:22:39	16.83	2.35	29.12	0.97	1.33	28.35
0:23:10	16.95	2.35	26.68	0.74	1.18	25.1

Table 32. Subject 023 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:23:40	16.65	2.51	26.71	0.67	1.27	27.06
0:24:12	16.65	2.49	28.81	0.82	1.37	29.19
0:24:42	16.8	2.44	31.86	1.06	1.46	31.13
0:25:13	16.87	2.39	29.26	0.98	1.32	28.1
0:25:43	16.71	2.44	28.12	1.08	1.32	28.14
0:26:14	16.47	2.51	32.95	1.22	1.64	34.89
0:26:45	16.86	2.39	31.53	0.88	1.43	30.39
0:27:16	16.8	2.46	34.34	0.95	1.57	33.5
0:27:47	16.98	2.38	32.9	0.89	1.44	30.64
0:28:18	17.04	2.35	32.99	1.22	1.42	30.26
0:28:49	17.03	2.36	25.97	0.87	1.12	23.83
0:29:20	16.82	2.43	23.61	0.81	1.08	22.91
0:29:50	16.73	2.37	24.89	0.58	1.17	24.85
0:30:22	16.95	2.25	17.44	0.44	0.78	16.5
0:00:36	18.18	1.45	10.74	0.29	0.33	7.09
0:01:06	17.6	1.72	8.92	0.16	0.34	7.14
0:01:37	17.39	1.79	15.87	0.33	0.64	13.54
0:02:08	16.89	1.99	18.17	0.38	0.83	17.74
0:02:38	16.54	2.15	22.71	0.57	1.13	24.11
0:03:09	16.3	2.23	26.69	0.95	1.41	29.98
0:03:40	16.37	2.31	31.8	0.96	1.64	34.97
0:04:11	16.55	2.36	29.86	0.96	1.47	31.24
0:04:42	16.55	2.47	38.15	1.36	1.87	39.69
0:05:12	16.95	2.35	35.15	0.93	1.55	33.03
0:05:43	16.83	2.42	37.78	1.45	1.72	36.59
0:06:14	17.01	2.36	36.09	1.16	1.57	33.35
0:06:45	16.95	2.41	36.94	1.27	1.63	34.64
0:07:15	16.86	2.46	39.11	1.22	1.76	37.43
0:00:36	18.19	1.44	8.15	0.14	0.25	5.36
0:01:07	17.46	1.86	8.3	0.12	0.32	6.89
0:01:37	17.23	2.02	9.27	0.17	0.38	8.19
0:02:08	17.1	2.06	9.5	0.23	0.41	8.71
0:02:39	16.9	2.14	8.78	0.18	0.4	8.48
0:03:10	16.96	2.11	10.94	0.23	0.49	10.42
0:03:40	16.86	2.12	10.09	0.14	0.46	9.87
0:04:11	16.83	2.13	10.59	0.23	0.49	10.43
0:04:42	16.92	2.1	11.3	0.36	0.51	10.89
0:05:12	17.07	2.08	10.03	0.16	0.44	9.26
0:05:43	17.02	2.09	10.31	0.17	0.45	9.64
0:06:14	16.92	2.12	12.19	0.32	0.55	11.72
0:06:45	16.81	2.12	12.44	0.38	0.58	12.31
0:07:16	16.76	2.13	12.76	0.38	0.6	12.79
0:07:47	16.61	2.17	12.97	0.38	0.63	13.5

Table 33. Subject 145 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:36	18.1	2.18	21.05	0.48	0.63	7.14
0:01:06	18.09	2.17	16.2	0.52	0.49	5.54
0:01:37	18.11	2.03	19.3	0.69	0.59	6.6
0:02:08	18.28	2.02	32.96	0.8	0.93	10.51
0:02:39	17.85	2.32	35.23	1.01	1.16	13.09
0:03:09	18.21	2.27	29.82	0.62	0.85	9.59
0:03:41	17.72	2.33	29.37	0.68	1.01	11.45
0:04:11	17.47	2.36	27.48	0.57	1.03	11.65
0:04:43	17.36	2.31	26.31	0.39	1.03	11.61
0:05:13	17.14	2.35	27.22	0.5	1.14	12.85
0:05:43	16.98	2.41	33.1	0.61	1.45	16.31
0:06:14	17.53	2.35	29.88	0.55	1.1	12.43
0:06:45	17.58	2.32	32.06	0.51	1.17	13.15
0:07:16	17.51	2.27	30.19	0.43	1.13	12.71
0:07:47	17.51	2.3	27.58	0.45	1.03	11.58
0:08:17	17.04	2.43	32.69	0.73	1.4	15.8
0:08:49	17.39	2.42	34.64	0.65	1.33	15.03
0:09:19	17.82	2.3	30.4	0.49	1.01	11.42
0:09:50	17.3	2.4	29.91	0.62	1.19	13.4
0:10:20	17.16	2.48	31.99	0.68	1.32	14.88
0:10:51	17.25	2.48	30.73	0.56	1.23	13.91
0:11:22	17.37	2.39	32.07	0.65	1.24	14.03
0:11:53	17.46	2.35	35.5	0.67	1.34	15.13
0:12:24	17.4	2.41	40.78	0.91	1.57	17.67
0:12:55	17.62	2.38	41.42	1.15	1.47	16.64
0:13:25	17.75	2.37	41.86	0.89	1.43	16.09
0:13:56	17.75	2.34	48.24	1.07	1.65	18.58
0:14:27	18.11	2.19	42.05	0.79	1.26	14.21
0:14:58	17.4	2.35	41.09	0.89	1.58	17.83
0:15:28	17.33	2.41	38.32	0.75	1.5	16.98
0:15:59	17.14	2.46	42.8	0.89	1.78	20.05
0:16:30	17.28	2.45	47.91	0.86	1.91	21.5
0:17:00	17.44	2.38	43.28	0.92	1.64	18.5
0:17:31	16.98	2.52	41.88	0.91	1.82	20.5
0:18:02	16.95	2.56	47.91	1.06	2.09	23.63
0:18:33	17.7	2.34	44.01	0.92	1.53	17.27
0:19:04	17.62	2.36	46.84	1	1.67	18.9
0:19:35	17.64	2.35	44.1	0.96	1.57	17.67
0:20:05	17.42	2.42	43.85	0.78	1.67	18.84
0:20:36	17.41	2.41	47.53	1.11	1.82	20.53
0:21:06	17.54	2.36	52.25	1.19	1.92	21.67
0:21:37	17.66	2.32	62.34	1.09	2.2	24.79
0:22:08	17.75	2.33	54.49	1.11	1.86	20.98
0:22:39	17.45	2.39	65.21	1.42	2.47	27.83
0:23:09	17.99	2.24	55.88	1.1	1.75	19.76
0:23:40	17.48	2.4	57.39	1.2	2.15	24.21

Table 33. Subject 145 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:24:11	17.37	2.42	57.06	1.36	2.21	24.96
0:24:42	17.5	2.42	58.25	1.46	2.16	24.37
0:25:13	17.32	2.48	54.08	1.2	2.12	23.94
0:25:43	17.44	2.44	63.01	1.34	2.38	26.87
0:26:14	18	2.26	62.97	1.23	1.96	22.1
0:26:45	17.8	2.28	66.22	1.54	2.23	25.17
0:27:15	17.93	2.24	60.77	1.41	1.95	22.04
0:27:46	17.55	2.34	69.41	1.42	2.54	28.67
0:28:17	18.07	2.21	67.61	1.33	2.06	23.21
0:28:48	18.01	2.2	70.39	1.44	2.19	24.75
0:29:18	17.93	2.19	53.85	1.22	1.73	19.56
0:29:49	17.03	2.45	73.54	1.75	3.15	35.58
0:30:20	17.96	2.29	95.52	1.87	3.02	34.12
0:30:51	18.39	2.15	98.05	1.85	2.6	29.35
0:31:22	18.31	2.14	90.45	1.64	2.49	28.09
0:31:53	17.93	2.28	100.5	1.97	3.21	36.24
0:32:24	18.33	2.19	119.8	2.49	3.25	36.69
0:32:55	18.59	2.06	106.9	2.06	2.59	29.28
0:33:25	18.22	2.16	95.53	1.84	2.74	30.89
0:33:56	18.04	2.25	107	2.23	3.29	37.1
0:34:27	18.33	2.13	109.8	2.11	3	33.83
0:34:57	18.33	2.1	54.66	1.27	1.5	16.89
0:35:29	17.92	2.2	11.72	0.24	0.38	4.28
0:35:59	18.13	2.06	12.64	0.29	0.38	4.28
0:36:29	18.01	2.15	13.31	0.34	0.42	4.71
0:37:00	17.98	2.15	12.66	0.28	0.4	4.52

Table 34. Subject 173 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.97	2.12	27.39	0.67	0.87	11.64
0:01:06	17.43	2.34	25.86	0.83	0.99	13.14
0:01:37	17.09	2.46	21.83	0.87	0.92	12.28
0:02:09	16.82	2.51	23.65	0.84	1.08	14.34
0:02:40	16.75	2.53	23.22	0.75	1.07	14.33
0:03:10	16.74	2.57	24.4	0.84	1.13	15.04
0:03:40	16.99	2.48	23.06	0.89	1	13.34
0:04:11	17	2.49	20.7	0.65	0.89	11.91
0:04:42	17.02	2.51	19.63	0.46	0.84	11.22
0:05:13	16.92	2.53	18.86	0.75	0.83	11.1
0:05:44	16.61	2.64	21.41	0.93	1.02	13.64
0:06:15	16.79	2.61	22.27	0.8	1.02	13.54
0:06:46	17.06	2.55	23.45	0.87	0.99	13.24
0:07:16	17.2	2.5	21.99	0.92	0.89	11.91
0:07:46	17.19	2.54	21.31	0.71	0.87	11.54
0:08:17	17.2	2.49	23.47	0.78	0.95	12.71
0:08:48	17.14	2.53	23.49	1.12	0.97	12.94
0:09:19	17.09	2.61	23.31	0.93	0.97	12.96
0:09:51	16.79	2.66	25.2	0.93	1.14	15.25
0:10:22	16.82	2.67	28.68	0.84	1.29	17.22
0:10:52	17.03	2.62	26.86	0.9	1.14	15.21
0:11:22	17.03	2.61	27.05	0.9	1.15	15.33
0:11:53	16.87	2.64	24.85	0.73	1.1	14.72
0:12:24	16.63	2.71	26.66	1.11	1.26	16.81
0:12:55	16.71	2.71	30.54	1.17	1.42	18.87
0:13:26	16.88	2.65	28.08	1.04	1.24	16.57
0:13:57	16.89	2.66	26.51	0.76	1.17	15.61
0:14:27	16.74	2.71	30.18	1.04	1.39	18.48
0:14:57	16.89	2.68	27.12	0.82	1.19	15.92
0:15:28	17.05	2.61	27.86	0.99	1.18	15.7
0:15:59	16.78	2.67	27.64	1.02	1.26	16.79
0:16:30	16.72	2.73	30.32	1.08	1.4	18.63
0:17:01	16.74	2.72	33.09	1.14	1.52	20.23
0:17:32	16.66	2.76	34.54	1.19	1.62	21.57
0:18:03	16.66	2.83	34.55	1.28	1.61	21.45
0:18:33	16.84	2.77	34.52	1.28	1.54	20.48
0:19:03	16.78	2.79	36.46	1.35	1.65	21.96
0:19:34	16.8	2.79	35.13	1.1	1.58	21.06
0:20:05	16.83	2.74	32.63	0.91	1.46	19.41
0:20:36	16.51	2.82	33.55	1.16	1.63	21.68
0:21:07	16.54	2.86	33.98	1.26	1.63	21.76
0:21:38	16.7	2.83	32.65	1.26	1.51	20.07
0:00:36	16.83	2.7	40.78	1.51	1.82	24.33
0:01:07	16.92	2.7	41.25	1.53	1.8	23.98
0:01:38	16.89	2.75	44.18	1.58	1.94	25.87

Table 34. Subject 173 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:02:08	16.95	2.74	46.49	1.66	2.01	26.74
0:02:38	16.89	2.8	53.48	1.84	2.34	31.19
0:03:09	17.22	2.74	54.56	1.82	2.17	28.96
0:03:40	17.22	2.77	53.99	1.74	2.15	28.61
0:04:12	17.1	2.81	54.47	1.82	2.24	29.85
0:04:42	17.26	2.77	57.77	1.81	2.26	30.14
0:05:13	17.22	2.8	55.68	1.74	2.21	29.41
0:05:43	17.12	2.82	55.03	1.83	2.25	29.96
0:06:14	17.13	2.81	49.53	1.83	2.01	26.86
0:06:45	16.95	2.91	46.99	1.62	2.01	26.79
0:07:16	17.81	2.68	42.82	1.34	1.39	18.51
0:07:47	18.09	2.56	32.29	1.15	0.94	12.57
0:08:18	18.42	2.38	25.2	0.84	0.64	8.56
0:08:49	18.51	2.33	47.86	0.7	1.17	15.66
0:09:19	18.55	2.28	31.8	0.53	0.77	10.21
0:09:49	18.55	2.24	25.55	0.75	0.62	8.27
0:10:20	18.27	2.29	12.32	0.46	0.34	4.54
0:10:51	18.02	2.41	11.57	0.4	0.35	4.7
0:11:22	17.73	2.49	15.2	0.37	0.52	6.89
0:11:54	17.75	2.44	27.98	0.74	0.95	12.62
0:12:25	18.45	2.13	26.53	0.95	0.69	9.14
0:12:54	17.86	2.4	35.65	1.32	1.16	15.49
0:13:25	17.17	2.56	43.45	1.45	1.77	23.67
0:13:56	17.09	2.54	48.86	1.48	2.05	27.27
0:14:26	17.12	2.55	55.68	1.64	2.31	30.79
0:14:57	17.28	2.56	60.46	1.78	2.39	31.83
0:15:29	17.17	2.64	64.37	1.84	2.62	34.89
0:16:00	17.4	2.6	65.87	1.65	2.5	33.27
0:16:30	17.38	2.65	67.27	1.98	2.55	33.99
0:17:00	17.41	2.63	69.23	2.1	2.6	34.71
0:17:31	17.43	2.62	69.93	2	2.61	34.83
0:18:02	17.4	2.62	69.21	1.92	2.61	34.87

Table 35. Subject 214 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	17.69	2.28	29.36	0.86	1.03	13.34
0:01:06	17.17	2.63	28.82	1.07	1.17	15.22
0:01:37	16.57	2.83	31.64	0.99	1.51	19.58
0:02:08	16.56	2.77	29.34	0.95	1.41	18.26
0:02:38	16.43	2.85	31.29	1.04	1.55	20.09
0:03:09	16.58	2.8	31.01	0.89	1.48	19.2
0:03:40	16.59	2.74	28.76	0.8	1.37	17.8
0:04:11	16.48	2.79	31.34	0.95	1.53	19.89
0:04:42	16.41	2.85	31.07	1.35	1.54	20.01
0:05:12	16.51	2.81	28.78	0.8	1.4	18.14
0:05:43	16.2	2.87	34.94	1.03	1.83	23.7
0:06:13	16.45	2.81	33.44	0.96	1.65	21.39
0:06:44	16.35	2.89	31.11	0.84	1.56	20.3
0:07:15	16.31	2.81	37.08	1.24	1.89	24.57
0:07:46	16.62	2.77	31.55	0.85	1.49	19.31
0:08:17	16.42	2.86	32.91	0.77	1.63	21.15
0:08:48	16.26	2.94	31.89	0.86	1.64	21.22
0:09:18	16.24	2.95	40.01	0.87	2.06	26.77
0:09:49	16.47	2.86	35.63	1.05	1.74	22.59
0:10:20	16.36	2.91	38.48	1.13	1.93	25.03
0:10:51	16.46	2.87	34.46	1.01	1.69	21.92
0:11:21	16.15	3	39.09	1.03	2.06	26.67
0:11:52	16.41	2.92	35.64	0.99	1.76	22.89
0:12:23	16.38	2.93	35.73	0.85	1.78	23.11
0:12:54	16.27	2.95	32.42	1.41	1.66	21.5
0:13:25	15.81	3.1	30.94	1.24	1.75	22.71
0:13:56	15.84	3.05	38.52	1.38	2.17	28.2
0:14:26	16.22	3.01	38.96	1.5	2.01	26.13
0:14:57	16.33	2.99	36.01	1.03	1.81	23.5
0:15:28	16.05	3.09	31.84	1.06	1.71	22.15
0:15:59	15.4	3.29	32.85	0.94	2.01	26.13
0:16:29	15.6	3.24	34.81	1.51	2.05	26.61
0:17:00	15.76	3.22	35.96	1	2.05	26.56
0:17:31	15.99	3.13	41.87	1.1	2.27	29.49
0:18:02	16.27	3.08	36.68	1.15	1.86	24.17
0:18:32	15.63	3.37	34.15	1.63	1.99	25.75
0:19:03	15.58	3.4	41.47	1.38	2.43	31.58
0:19:34	15.81	3.31	38.29	1.28	2.15	27.84
0:20:05	15.95	3.26	43.23	2.16	2.35	30.52
0:20:35	16.02	3.24	39.02	1.39	2.09	27.14
0:21:06	16.14	3.19	40.6	1.62	2.12	27.51
0:21:37	16.11	3.15	45	1.29	2.37	30.75
0:22:07	16.14	3.14	43.2	1.6	2.26	29.3
0:22:38	16.31	3.16	40.9	1.36	2.05	26.58
0:23:09	16.17	3.11	49.3	1.97	2.57	33.32
0:23:40	16.68	2.93	54.23	0.9	2.5	32.39

Table 35. Subject 214 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:24:11	16.25	3.09	49.14	1.36	2.51	32.57
0:24:41	16.39	3.02	56.21	1.87	2.78	36.1
0:25:12	16.52	2.94	54.71	2.1	2.63	34.09
0:25:43	16.24	3.16	55.11	1.97	2.82	36.52
0:26:14	16.32	3.14	57.11	2.38	2.86	37.1
0:26:45	16.4	3.14	66.28	2.21	3.26	42.22
0:27:16	16.47	3.1	68.52	2.74	3.31	42.93
0:27:46	16.35	3.2	69.58	2.9	3.45	44.73
0:28:17	16.24	3.25	71.94	2.88	3.66	47.41
0:28:48	16.2	3.26	77.42	3.52	3.97	51.5
0:29:18	16.35	3.19	76.39	2.31	3.79	49.12
0:29:49	16.31	3.24	75.94	2.53	3.79	49.22
0:30:21	16.29	3.25	79.68	2.75	4	51.9
0:30:51	16.4	3.21	81.77	2.92	4	51.89
0:31:21	16.41	3.18	79.08	2.82	3.86	50.12
0:31:52	16.32	3.23	81.86	2.92	4.08	52.95
0:32:23	16.57	3.13	80.7	2.6	3.79	49.18
0:32:53	16.46	3.16	83.07	3.32	4.01	52
0:33:24	16.49	3.14	81.12	3.12	3.89	50.45
0:33:55	16.51	3.08	80.09	2.76	3.83	49.63
0:34:26	16.58	3.04	80.44	2.51	3.79	49.14
0:34:56	16.65	3	74.88	3.12	3.47	44.99
0:35:27	16.36	3.09	72.54	2.59	3.6	46.74
0:35:58	16.39	3.09	75.1	2.5	3.7	48.01
0:36:29	16.61	2.95	74.77	2.77	3.5	45.45
0:37:00	16.68	2.88	69.64	2.58	3.22	41.7
0:37:31	16.35	2.97	66.89	2.57	3.35	43.49
0:38:01	16.08	3.08	65.47	1.77	3.49	45.28

Table 36. Subject 221 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:37	16.86	2.46	20.81	0.56	0.94	12.49
0:01:07	15.68	2.86	24.86	0.58	1.47	19.54
0:01:37	15.29	2.91	23.76	0.53	1.51	20.17
0:02:08	15.33	2.95	24.97	0.42	1.58	21.02
0:02:39	15.31	2.93	25.96	0.84	1.65	21.95
0:03:10	15.81	2.92	24.25	0.55	1.38	18.45
0:03:41	15.83	2.93	21.61	0.58	1.23	16.36
0:04:11	15.74	2.96	22.84	0.65	1.32	17.63
0:04:41	15.96	2.93	21.43	0.63	1.18	15.75
0:05:13	15.93	2.95	22.8	0.57	1.27	16.89
0:05:43	15.79	2.97	21.38	0.56	1.22	16.31
0:06:15	15.75	3	24.63	0.63	1.42	18.92
0:06:46	15.88	3	24.96	0.66	1.4	18.65
0:07:15	15.75	3.02	26.5	0.74	1.53	20.36
0:07:46	15.45	3.07	26.37	0.82	1.61	21.53
0:08:17	15.48	3.13	27.62	0.77	1.68	22.37
0:08:48	15.83	3.03	27.47	0.69	1.55	20.71
0:09:19	15.68	3.09	30.15	1.08	1.76	23.44
0:09:51	15.81	3.03	25.03	0.54	1.42	18.97
0:10:20	15.46	3.15	29.48	0.87	1.8	23.93
0:10:51	15.72	3.08	29.11	0.66	1.68	22.44
0:11:22	15.63	3.12	31.98	0.94	1.88	25.12
0:11:52	15.7	3.1	32.41	1.2	1.88	25.07
0:12:24	15.69	3.11	29.77	1.06	1.73	23.06
0:12:55	15.41	3.23	33.89	1.09	2.08	27.75
0:13:25	15.71	3.13	36.69	1.18	2.12	28.29
0:13:56	15.9	3.11	36.03	1.16	2	26.61
0:14:27	15.66	3.21	41.01	1.37	2.39	31.86
0:14:57	15.93	3.15	40.83	1.57	2.24	29.93
0:15:29	15.97	3.12	43.49	1.5	2.37	31.59
0:16:00	15.99	3.17	43.17	1.6	2.34	31.18
0:16:30	16.04	3.13	42.39	1.51	2.28	30.34
0:00:35	19.66	0.82	11.54	0.5	0.16	2.15
0:01:07	16.81	2.49	14.52	0.39	0.66	8.84
0:01:37	16.59	2.69	15.02	0.39	0.72	9.58
0:02:09	16.5	2.67	17.06	0.5	0.84	11.15
0:02:40	16.52	2.8	14.05	0.37	0.68	9.06
0:03:09	17.11	2.66	13.69	0.47	0.57	7.55
0:03:40	17.14	2.69	10.99	0.28	0.45	5.99
0:04:11	17.16	2.63	13.3	0.28	0.54	7.24
0:04:42	16.9	2.66	21.21	0.34	0.93	12.44
0:05:13	16.72	2.71	22.21	0.77	1.03	13.68
0:05:44	16	2.82	26.24	0.62	1.44	19.22
0:06:14	14.89	2.97	32.87	0.63	2.25	30.06
0:06:44	14.8	3.01	42.66	0.85	2.97	39.61

Table 36. Subject 221 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:07:15	15.06	3.15	47.55	1.76	3.14	41.84
0:07:46	15.72	3.19	52.17	1.41	3	39.99
0:08:18	16.03	3.15	56.15	1.75	3.02	40.23
0:08:48	16.29	3.1	58	1.81	2.93	39.06
0:09:18	16.31	3.09	58.62	1.78	2.95	39.39
0:09:48	16.49	3.02	60.82	1.9	2.94	39.16
0:10:20	16.39	3.03	61.91	1.88	3.06	40.84
0:10:51	16.46	3.03	62	1.77	3.02	40.21
0:11:22	16.58	2.98	67.58	1.78	3.19	42.6
0:11:52	16.65	2.94	68.34	1.75	3.17	42.33
0:12:23	16.72	2.88	68.95	1.86	3.15	42.02
0:00:36	19.93	0.69	13.38	0.36	0.15	1.94
0:01:07	17.37	2.1	11.9	0.36	0.47	6.28
0:01:38	16.89	2.4	11.15	0.46	0.5	6.66
0:02:08	16.73	2.45	19.12	0.33	0.89	11.9
0:02:39	16.95	2.44	22.2	0.47	0.98	13
0:03:09	15.62	2.66	30.25	0.76	1.82	24.3
0:03:40	15.33	2.75	36.01	0.92	2.29	30.56
0:04:11	15.61	2.78	49.56	1.21	2.98	39.68
0:04:43	16.06	2.78	53.16	1.66	2.89	38.49
0:05:14	16.18	2.85	63.09	1.66	3.32	44.27
0:05:44	16.5	2.83	68.91	1.86	3.35	44.64
0:06:14	16.67	2.86	68.18	1.75	3.16	42.15
0:06:45	16.63	2.87	74.26	1.86	3.48	46.4
0:07:16	16.95	2.78	84.78	1.84	3.66	48.74
0:07:47	17.12	2.8	88.83	2.02	3.63	48.45
0:08:18	17.21	2.81	99.49	2.07	3.94	52.59
0:08:48	17.44	2.72	105.5	2.2	3.91	52.1

Table 37. Subject 224 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:35	16.5	2.35	18.28	0.52	0.91	14.05
0:01:06	15.98	2.47	19.38	0.45	1.09	16.73
0:01:37	15.58	2.5	20.28	0.47	1.24	19.06
0:02:08	15.5	2.62	18.3	0.63	1.13	17.43
0:02:38	15.57	2.63	20.2	0.61	1.23	18.91
0:03:10	15.58	2.59	16.34	0.54	1	15.31
0:03:40	15.18	2.78	14.28	0.43	0.93	14.37
0:04:11	14.92	2.92	18.13	0.53	1.24	19.06
0:04:42	15.48	2.77	19	0.7	1.17	18.03
0:05:13	15.82	2.73	18.48	0.62	1.06	16.34
0:05:44	15.89	2.72	17.33	0.6	0.98	15.11
0:06:15	15.8	2.7	16.92	0.63	0.98	15.06
0:06:46	16.02	2.67	16.93	0.55	0.93	14.35
0:07:16	15.94	2.72	17.45	0.55	0.98	15.03
0:07:47	15.96	2.73	22.45	0.72	1.25	19.23
0:08:17	16.28	2.63	22.97	0.82	1.19	18.34
0:08:48	16.31	2.64	25.76	0.92	1.33	20.44
0:09:19	16.42	2.6	24.24	0.78	1.22	18.75
0:09:50	16.47	2.57	23.29	0.8	1.16	17.8
0:10:21	16.26	2.6	22.91	0.64	1.2	18.42
0:10:51	16.18	2.61	26.11	0.75	1.39	21.36
0:11:22	16.27	2.59	23.77	0.72	1.24	19.08
0:11:53	16.27	2.6	27.93	0.82	1.46	22.4
0:12:24	16.45	2.57	27.39	0.83	1.37	21.03
0:12:54	16.27	2.6	26.84	0.84	1.4	21.54
0:13:25	16.26	2.6	26.55	0.68	1.39	21.32
0:13:56	16.17	2.64	30.21	1.01	1.61	24.79
0:14:27	16.37	2.6	28.86	0.8	1.47	22.6
0:14:58	16.3	2.6	28.87	0.82	1.5	23.01
0:15:28	16.23	2.57	31.12	0.97	1.64	25.27
0:15:59	16.31	2.58	28.7	0.93	1.48	22.83
0:16:30	16.24	2.57	31.52	0.83	1.66	25.49
0:17:01	16.47	2.51	28.61	0.79	1.43	21.96
0:17:32	16.33	2.57	30.49	0.92	1.57	24.13
0:18:02	16.37	2.55	30.87	0.88	1.58	24.24
0:18:33	16.38	2.54	31.92	0.86	1.63	25.01
0:19:04	16.43	2.53	30.77	0.79	1.55	23.8
0:19:34	16.47	2.53	31.7	0.74	1.58	24.27
0:20:05	16.41	2.55	35.29	0.93	1.78	27.45
0:20:36	16.61	2.49	35.08	0.97	1.69	25.97
0:00:36	15.61	2.65	28.77	0.82	1.74	28.92
0:01:06	15.82	2.69	27.66	0.79	1.59	26.56
0:01:37	15.65	2.78	31.13	0.71	1.85	30.86
0:02:07	15.89	2.76	32.53	0.86	1.84	30.67
0:02:38	16.07	2.77	35.64	0.99	1.93	32.16

Table 37. Subject 224 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:03:09	16.22	2.8	37.99	0.97	1.98	33.06
0:03:40	16.36	2.76	33.94	0.89	1.71	28.57
0:04:11	16	2.87	39.79	1.17	2.18	36.37
0:04:42	16.32	2.82	40.15	1.09	2.04	34.05
0:05:13	16.39	2.8	41.07	1.03	2.06	34.31
0:05:43	16.38	2.81	42.67	1.02	2.14	35.67
0:06:14	16.49	2.8	42.52	0.92	2.08	34.63
0:06:45	16.52	2.77	47.9	1.06	2.32	38.72
0:07:15	16.66	2.73	49.6	1.1	2.32	38.73
0:07:45	16.69	2.73	50.79	1.13	2.36	39.35
0:08:16	16.76	2.69	54.25	1.15	2.48	41.26
0:08:47	16.79	2.67	51.87	0.98	2.35	39.23
0:09:18	16.31	2.85	58.79	0.95	2.99	49.88
0:09:48	16.72	2.69	57.94	1.16	2.68	44.66
0:10:19	16.91	2.62	64.74	1.29	2.85	47.46
0:10:50	17.1	2.55	61.45	1.2	2.56	42.73
0:11:21	17.13	2.53	62.67	1.28	2.6	43.3

Table 38. Subject 230 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:36	17.36	2.22	21.34	0.58	0.84	13.23
0:01:07	16.89	2.38	23.65	0.56	1.06	16.72
0:01:38	16.81	2.47	24.11	0.69	1.1	17.36
0:02:09	16.53	2.52	25.91	0.74	1.27	19.98
0:02:39	16.55	2.53	21.07	0.7	1.03	16.19
0:03:11	16.58	2.53	25.03	0.7	1.21	19.1
0:03:41	16.66	2.48	19.53	0.72	0.93	14.61
0:04:12	16.54	2.53	19.99	0.69	0.98	15.41
0:04:43	16.49	2.55	23.43	0.94	1.16	18.27
0:05:13	16.85	2.45	18.32	0.76	0.83	13.05
0:05:44	16.58	2.72	19.39	0.81	0.93	14.63
0:06:15	16.44	2.67	24.96	0.81	1.24	19.57
0:06:46	16.68	2.46	21.9	0.63	1.04	16.33
0:07:16	16.76	2.52	23.99	0.73	1.11	17.43
0:07:47	16.42	2.56	29.06	0.68	1.46	23.05
0:08:18	16.44	2.54	28.74	0.8	1.44	22.67
0:08:48	16.6	2.53	29.94	0.88	1.44	22.73
0:09:20	16.52	2.51	29.58	0.74	1.45	22.9
0:09:51	16.6	2.56	29.08	0.77	1.4	22.01
0:10:21	16.54	2.56	29.12	0.86	1.42	22.4
0:10:52	16.62	2.56	29.22	0.91	1.4	22
0:11:23	16.66	2.53	27.53	0.72	1.3	20.54
0:11:53	16.57	2.6	26.1	0.64	1.26	19.89
0:12:24	16.8	2.48	18.95	0.61	0.87	13.67
0:12:55	16.17	2.77	21.89	0.58	1.16	18.26
0:13:25	15.89	2.86	27.63	0.81	1.55	24.48
0:13:56	16.4	2.65	26.79	0.74	1.35	21.25
0:14:27	16.71	2.49	26.65	0.81	1.25	19.63
0:14:58	16.38	2.63	28.41	0.81	1.44	22.66
0:15:29	16.46	2.63	31.48	1.05	1.56	24.61
0:16:00	16.73	2.56	30.04	0.73	1.4	21.98
0:16:29	16.45	2.62	29.84	0.85	1.49	23.4
0:17:01	16.25	2.72	35.75	0.97	1.86	29.33
0:17:31	16.5	2.64	34.33	0.84	1.69	26.57
0:18:02	16.66	2.62	33.96	0.92	1.6	25.22
0:18:33	16.73	2.61	33.11	0.87	1.53	24.14
0:19:04	16.53	2.66	33.55	0.99	1.63	25.73
0:19:34	16.43	2.69	33.83	0.91	1.69	26.58
0:00:36	17.22	2.36	20.13	0.5	0.82	12.91
0:01:07	16.74	2.52	24.5	0.51	1.14	17.9
0:01:38	16.4	2.6	26.78	0.84	1.35	21.27
0:02:08	16.1	2.75	31.13	0.69	1.68	26.44
0:02:39	16.23	2.77	30.48	0.71	1.59	25.07
0:03:10	16.2	2.88	36.42	0.66	1.9	29.97
0:03:40	16.45	2.93	39.08	0.83	1.92	30.17

Table 38. Subject 230 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:04:11	16.61	2.99	40.87	0.87	1.91	30.13
0:04:42	16.79	2.97	41.65	0.82	1.85	29.2
0:05:13	16.73	3.06	46.12	0.96	2.08	32.75
0:05:44	17.01	3.01	47.2	0.87	1.97	31.02
0:06:14	16.83	3.11	53.72	1.17	2.35	36.95
0:06:45	17.23	2.95	54.49	1.11	2.13	33.47
0:07:16	17.31	2.89	58.9	1.25	2.25	35.39
0:07:46	17.41	2.84	56.5	1.2	2.09	32.95
0:08:17	17.36	2.84	63	1.21	2.37	37.39
0:08:49	17.56	2.75	63.64	1.27	2.26	35.53
0:09:19	17.68	2.68	56.56	1.03	1.93	30.39
0:09:50	17.28	2.8	43.93	0.95	1.7	26.85
0:10:21	17.21	2.9	37.41	0.85	1.48	23.28
0:10:51	17.72	2.8	22.22	0.62	0.74	11.64
0:11:22	18.36	2.43	4.55	0.16	0.12	1.88

Table 39. Subject 231 levels determination test.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:36	17.57	2.05	16.95	0.47	0.63	10.19
0:01:06	17.08	2.19	19.08	0.44	0.82	13.28
0:01:37	16.7	2.4	15.88	0.38	0.75	12.17
0:02:07	16.61	2.36	18.42	0.54	0.89	14.48
0:02:38	16.36	2.4	17.8	0.52	0.92	14.87
0:03:09	16.36	2.39	17.22	0.32	0.89	14.41
0:03:40	16.23	2.44	19.86	0.62	1.05	17.06
0:04:11	16.32	2.44	19.7	0.64	1.02	16.58
0:04:42	16.37	2.44	18.57	0.43	0.95	15.44
0:05:12	16.37	2.44	18.36	0.52	0.94	15.26
0:05:43	16.42	2.44	20.3	0.48	1.03	16.68
0:06:14	16.37	2.46	19.72	0.55	1.01	16.4
0:06:45	16.16	2.53	23.34	0.65	1.25	20.32
0:07:15	16.34	2.51	23.47	0.69	1.21	19.61
0:07:46	16.48	2.49	24.23	0.62	1.21	19.56
0:08:17	16.43	2.5	23.67	0.85	1.19	19.33
0:08:47	16.38	2.47	24	0.75	1.23	19.88
0:09:18	16.23	2.5	23.61	0.64	1.25	20.23
0:09:49	16.36	2.45	24.63	0.51	1.27	20.5
0:10:20	16.29	2.46	28.19	0.7	1.47	23.88
0:10:51	16.26	2.51	32.12	0.71	1.69	27.32
0:11:21	16.33	2.5	32.42	0.7	1.67	27.14
0:11:52	16.25	2.52	34.12	0.74	1.79	29.09
0:12:24	16.24	2.56	32.49	0.71	1.71	27.7
0:12:54	16.03	2.63	34.7	0.85	1.91	31.01
0:13:25	16.37	2.57	33.67	0.62	1.72	27.81
0:13:56	16.37	2.55	34.9	0.79	1.78	28.83
0:14:26	16.3	2.59	35.65	0.83	1.85	29.92
0:14:57	16.5	2.61	37.03	0.93	1.82	29.54
0:15:28	16.56	2.61	41.71	0.93	2.02	32.73
0:15:59	16.33	2.69	43.79	1.22	2.24	36.33
0:16:29	16.38	2.76	46.75	0.99	2.35	38.16
0:17:00	16.45	2.73	49.44	1.15	2.45	39.72
0:17:31	16.54	2.71	48.64	1.13	2.36	38.21
0:18:01	16.59	2.68	45.91	1.31	2.2	35.65
0:18:33	16.61	2.68	47.43	1.05	2.26	36.58
0:19:03	16.75	2.59	47.2	1.05	2.18	35.28
0:19:34	16.59	2.56	45.17	1.08	2.18	35.27
0:00:36	17.54	2.07	15.41	0.32	0.58	9.36
0:01:06	17.02	2.2	16.26	0.54	0.71	11.51
0:01:37	16.77	2.24	18.38	0.29	0.86	13.95
0:02:08	16.76	2.2	18.34	0.35	0.86	13.96
0:02:39	16.59	2.28	15.95	0.64	0.78	12.66
0:03:09	16.69	2.25	15.33	0.61	0.73	11.87
0:03:40	16.77	2.22	14.38	0.4	0.67	10.91

Table 39. Subject 231 levels determination test (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:04:11	16.98	2.15	14.48	0.37	0.64	10.41
0:04:41	16.89	2.15	15.15	0.34	0.69	11.17
0:05:13	16.93	2.11	10.68	0.21	0.48	7.81
0:05:43	16.94	2.13	3.04	0.16	0.14	2.21
0:06:14	17.1	2.21	2.92	0.36	0.12	2.02
0:06:46	17.15	2.2	2.87	0.19	0.12	1.96
0:07:17	17.24	2.14	2.95	0.37	0.12	1.96

Table 40. Subject 001 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:37	16.94	2.17	21.47	0.86	0.96	10.46		
0:01:07	16.44	2.36	21.8	0.84	1.1	12.01	66	
0:01:37	15.69	2.49	21.48	0.77	1.28	13.96		
0:02:08	15.44	2.52	22.02	0.92	1.38	15.04	69	6
0:02:39	15.3	2.57	22.47	0.77	1.45	15.75		
0:03:09	15.47	2.61	23.43	0.94	1.46	15.84	65	
0:03:41	15.55	2.58	23.17	1.01	1.42	15.45		
0:04:11	15.63	2.6	22.35	0.93	1.35	14.64	68	6
0:04:42	15.71	2.58	23.66	1.03	1.4	15.25		
0:05:13	16.07	2.52	24.44	1.11	1.34	14.56	68	
0:05:43	16.1	2.51	25.72	1.22	1.4	15.24		
0:06:14	16.15	2.51	23.99	0.83	1.29	14.05	70	6
0:06:45	16.14	2.5	26.53	1.06	1.44	15.6		
0:07:15	16.33	2.47	28.46	1.29	1.47	16.01		
0:07:47	16.25	2.53	28.8	0.93	1.51	16.46	76	
0:08:18	15.96	2.56	30.81	1.23	1.73	18.83		
0:08:48	16.01	2.5	31.75	1.18	1.77	19.23	78	7
0:09:19	16.07	2.5	30.94	1.29	1.7	18.47		
0:09:49	15.99	2.51	31.59	1.26	1.77	19.2	83	
0:10:20	15.95	2.53	29.9	1.3	1.68	18.31		
0:10:51	15.84	2.56	28.26	1.23	1.63	17.73	83	7
0:11:21	15.72	2.61	27.67	1.06	1.64	17.78		
0:11:52	15.67	2.62	28.64	1.15	1.71	18.58	82	
0:12:24	15.8	2.6	30.58	1.27	1.78	19.32		
0:12:54	15.94	2.56	30.62	1.46	1.73	18.76	82	7
0:13:26	15.94	2.59	36.11	1.2	2.03	22.12		
0:13:55	16.4	2.49	37.59	1.34	1.91	20.74		
0:14:26	16.47	2.49	39.53	1.36	1.97	21.45	95	
0:14:57	16.1	2.53	36.54	1.35	1.99	21.62		
0:15:27	15.84	2.59	41.06	1.47	2.36	25.68	101	8
0:15:58	16.11	2.57	43.24	1.44	2.34	25.49		
0:16:30	16.39	2.48	44.53	1.44	2.27	24.68	100	
0:17:00	16.42	2.45	43.56	1.36	2.2	23.96		
0:17:31	16.32	2.46	40.31	1.3	2.09	22.7	98	8
0:18:01	16.16	2.51	41.34	1.15	2.22	24.16		
0:18:32	16.02	2.55	40.6	1.4	2.25	24.46	101	
0:19:03	16.1	2.55	42.12	1.32	2.29	24.88		
0:19:34	16.23	2.55	38.27	1.2	2.02	21.93	98	8
0:20:05	15.89	2.61	43.41	1.4	2.47	26.82		
0:20:36	16.31	2.52	50.71	1.58	2.63	28.56		
0:21:07	16.26	2.55	52.13	1.58	2.73	29.66	123	
0:21:38	16.02	2.58	58.93	1.73	3.26	35.44		
0:22:08	15.99	2.6	57.68	1.7	3.21	34.9	126	11
0:22:38	16.02	2.63	61.36	1.7	3.39	36.86		
0:23:09	15.97	2.66	60.06	1.4	3.35	36.37	124	
0:23:40	16.1	2.62	56.64	1.72	3.07	33.36		

Table 40. Subject 001 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:11	15.86	2.73	61.46	1.66	3.5	38.07	126	11
0:24:42	16.1	2.63	60.68	1.56	3.29	35.79		
0:25:13	16.03	2.65	58.5	1.67	3.22	35	131	
0:25:44	16.01	2.68	61.12	1.75	3.37	36.67		
0:26:14	16.11	2.63	65.23	1.67	3.53	38.36		
0:26:45	16.28	2.59	68.79	1.56	3.58	38.92		
0:27:15	16.57	2.51	75.61	1.89	3.67	39.89		
0:27:46	16.56	2.54	76.63	1.7	3.73	40.53	152	
0:28:17	16.66	2.51	89.94	1.76	4.26	46.32		
0:28:49	16.72	2.54	89.25	1.82	4.16	45.2	156	13
0:29:20	16.62	2.56	92.9	1.9	4.44	48.27		
0:29:51	16.66	2.54	87.63	1.95	4.15	45.16	157	
0:30:20	16.48	2.62	94.58	1.85	4.68	50.86		
0:30:51	16.69	2.54	93.04	1.94	4.37	47.51	160	15
0:31:22	16.64	2.57	92.3	2.01	4.38	47.66		
0:31:53	16.45	2.67	89.08	1.71	4.42	48.05	158	
0:32:23	16.47	2.67	91.98	2	4.54	49.4		
0:32:55	16.44	2.68	87.9	1.95	4.37	47.5	158	14
0:33:26	16.35	2.7	89.73	1.76	4.57	49.62		

Table 41. Subject 002 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	16.96	2.15	15.32	0.33	0.68	11.79		
0:01:07	16.47	2.37	15.16	0.34	0.76	13.12	89	
0:01:37	16.29	2.46	15.79	0.35	0.83	14.23	97	9
0:02:08	16.04	2.51	17.12	0.36	0.95	16.33		
0:02:38	15.96	2.49	16.33	0.39	0.92	15.87		
0:03:09	16.02	2.51	17.39	0.58	0.97	16.65	86	
0:03:40	16.06	2.5	15.99	0.4	0.88	15.2	92	9
0:04:11	15.94	2.52	17.18	0.48	0.97	16.73	88	
0:04:42	15.95	2.5	15.12	0.49	0.85	14.74		
0:05:12	15.85	2.55	16.07	0.55	0.93	15.96		
0:05:43	15.8	2.56	17.03	0.59	0.99	17.09		
0:06:14	15.89	2.56	17.15	0.64	0.98	16.88		
0:06:44	15.95	2.54	21.38	0.74	1.2	20.76	104	
0:07:15	16.16	2.49	19.5	0.63	1.05	18.08	105	
0:07:46	16.06	2.53	19.22	0.58	1.06	18.22	108	9
0:08:17	15.78	2.59	21.06	0.66	1.23	21.19	106	
0:08:48	15.67	2.62	20.24	0.78	1.21	20.85	102	
0:09:18	15.74	2.62	19.63	0.56	1.15	19.91	105	
0:09:50	15.61	2.68	20.31	0.73	1.22	21.1	111	9
0:10:20	15.6	2.66	21.57	0.67	1.31	22.51		
0:10:51	15.73	2.67	23.34	0.69	1.37	23.67	122	
0:11:23	15.93	2.68	24.29	0.71	1.37	23.56		11
0:11:53	15.52	2.8	27.12	0.9	1.66	28.58	133	
0:12:23	15.56	2.79	27.42	0.86	1.66	28.68	133	
0:12:54	15.75	2.8	28.32	0.94	1.65	28.43	135	
0:13:24	15.84	2.82	29.36	0.95	1.67	28.85		11
0:13:56	15.82	2.8	28.8	0.82	1.65	28.46		
0:14:26	15.75	2.8	29.12	1.08	1.69	29.2	142	
0:14:57	15.94	2.82	30.4	0.95	1.69	29.21	143	
0:15:27	16	2.8	29.92	0.97	1.65	28.36	148	15
0:15:58	15.81	2.89	29.74	0.93	1.7	29.32		
0:16:29	15.73	2.95	25.68	0.58	1.49	25.68	146	
0:17:00	15.56	3.07	30.64	0.9	1.83	31.63	150	
0:17:31	15.95	2.96	36.59	0.94	2.02	34.87	150	15
0:18:01	16.47	2.8	37.73	0.92	1.85	31.95	148	
0:18:32	16.61	2.74	37.43	0.87	1.78	30.66	149	
0:19:03	16.48	2.74	34.11	0.76	1.68	28.88	148	
0:19:34	16.18	2.79	36.62	1.02	1.93	33.3	153	15
0:20:05	16.43	2.72	38.17	0.95	1.9	32.75		
0:20:36	16.57	2.67	36.43	0.96	1.75	30.26	149	
0:21:07	16.4	2.76	38.12	0.98	1.91	32.94	150	
0:21:37	16.53	2.7	27.24	0.63	1.32	22.8		15

Table 42. Subject 023 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.58	1.95	11.68	0.23	0.44	9.26	97	
0:01:06	17.52	2.01	12.23	0.3	0.46	9.86	96	
0:01:37	17.49	2.02	10.97	0.37	0.42	8.92	99	
0:02:08	17.2	2.13	11.57	0.24	0.48	10.24	94	8
0:02:40	17.05	2.14	12.59	0.29	0.55	11.65	98	
0:03:10	17.12	2.08	11.04	0.28	0.47	10.04	98	
0:03:41	17.07	2.12	11.21	0.29	0.48	10.31	96	
0:04:11	16.97	2.19	10.52	0.26	0.47	9.93	199	8
0:04:42	16.85	2.22	11.62	0.26	0.53	11.33	95	
0:05:13	17.02	2.15	11.55	0.58	0.51	10.78	199	
0:05:43	17	2.19	11.65	0.61	0.51	10.9	98	
0:06:14	17.18	2.16	10.31	0.19	0.43	9.16	106	8
0:06:45	16.88	2.33	10.79	0.27	0.49	10.38		
0:07:17	16.95	2.25	12.32	0.23	0.55	11.64		
0:07:47	17.23	2.07	11.62	0.22	0.48	10.25		
0:08:18	17.36	2.05	13.38	0.3	0.53	11.32	95	
0:08:48	17.28	2.09	11.3	0.31	0.46	9.79	96	
0:09:20	16.97	2.28	14.6	0.36	0.64	13.7	100	
0:09:50	16.88	2.29	13.77	0.37	0.62	13.27	106	
0:10:20	16.96	2.26	13.4	0.3	0.59	12.64	100	
0:10:52	17.07	2.23	13.47	0.35	0.58	12.32	103	
0:11:22	17.05	2.27	13.78	0.31	0.59	12.65	101	
0:11:53	16.93	2.26	14	0.38	0.63	13.31	103	10
0:12:25	17.03	2.25	15.46	0.53	0.67	14.31	102	
0:12:55	17.17	2.21	13.7	0.38	0.57	12.19	101	
0:13:25	17.18	2.25	15.05	0.47	0.63	13.31	101	
0:13:57	17.08	2.28	14.36	0.33	0.61	13.04	100	10
0:14:27	17.17	2.24	13.9	0.25	0.58	12.33		
0:14:58	17.23	2.22	17.35	0.56	0.71	15.14		
0:15:29	17.39	2.2	16.34	0.4	0.64	13.58	120	
0:15:59	17.36	2.23	17.29	0.3	0.68	14.47	123	
0:16:31	16.91	2.39	20.27	0.81	0.9	19.23	121	
0:17:02	16.93	2.35	18.65	0.49	0.83	17.63	124	11
0:17:32	16.99	2.36	20.94	0.7	0.91	19.43	123	
0:18:02	17.1	2.3	19.68	0.76	0.84	17.78	122	
0:18:33	17.07	2.31	22.51	0.61	0.96	20.46	125	
0:19:04	17.28	2.21	21.71	0.66	0.88	18.69	122	12
0:19:35	17.32	2.24	21.69	0.75	0.86	18.36	124	
0:20:05	17.33	2.21	18.85	0.82	0.75	15.93		
0:20:36	17.12	2.3	16.54	0.49	0.7	14.83	122	
0:21:08	16.93	2.36	17.71	0.48	0.79	16.73	124	12
0:21:39	16.58	2.45	17.46	0.55	0.85	18.05	122	
0:22:09	16.69	2.43	18.66	0.55	0.88	18.77	123	
0:22:39	16.63	2.46	19.5	0.63	0.94	19.91	122	12
0:23:10	16.94	2.39	20.08	0.67	0.89	18.87		
0:23:41	17.29	2.25	15.9	0.51	0.64	13.57		

Table 42. Subject 023 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.54	1.93	10.64	0.13	0.4	8.57		
0:01:06	17.59	2.01	8.28	0.09	0.31	6.51		
0:01:38	17.71	1.96	6.83	0.08	0.24	5.18		
0:02:09	17.52	1.93	11.57	0.16	0.44	9.38		
0:02:39	17.48	1.95	15.99	0.33	0.62	13.13		
0:03:09	17.77	1.95	15.99	0.28	0.56	11.85		
0:03:41	17.52	2.12	20.42	0.49	0.77	16.31		
0:04:11	17.01	2.19	21.69	0.77	0.95	20.23	144	
0:04:42	16.83	2.22	23.31	0.8	1.07	22.84	143	
0:05:13	16.87	2.28	26.72	0.67	1.21	25.81	145	
0:05:43	16.84	2.38	27.24	0.85	1.24	26.4	148	14
0:06:15	17.13	2.44	29.69	1.02	1.24	26.34	147	
0:06:46	17.24	2.33	28.23	1.13	1.14	24.35	147	
0:07:16	17.16	2.36	28.17	1.66	1.17	24.88	147	
0:07:46	17.23	2.43	27.18	1.01	1.1	23.35	150	15
0:08:18	17.07	2.51	32.14	1	1.36	28.95	151	
0:08:48	17.28	2.44	29.8	1.3	1.18	25.21	150	
0:09:19	17.27	2.44	29.59	1.18	1.18	25.16	142	15
0:09:50	17.25	2.42	30.16	1.01	1.21	25.76		
0:10:20	17.38	2.26	26.13	1.05	1.02	21.69		
0:10:52	17.44	2.23	21.84	0.91	0.84	17.82		
0:11:23	17.75	2.13	16.66	0.48	0.58	12.27		
0:11:53	17.95	2.08	12.26	0.26	0.39	8.4		
0:12:24	17.69	2.1	11.62	0.16	0.41	8.79		
0:12:54	17.78	2.1	9.68	0.09	0.33	7.07		
0:13:25	17.84	2.14	9.14	0.11	0.31	6.5		
0:13:57	17.76	2.09	15.47	0.4	0.54	11.41		
0:14:27	17.94	2	19.83	0.47	0.65	13.74		
0:14:58	18.1	1.97	19.11	0.49	0.59	12.49		
0:15:29	17.48	2.19	22.1	0.55	0.84	17.83		
0:16:00	16.97	2.19	28	0.93	1.24	26.44	155	
0:16:30	16.93	2.2	29.75	1.35	1.33	28.39	159	
0:17:01	16.9	2.3	33.25	1.33	1.5	31.81	162	
0:17:32	17.27	2.37	33.94	1.41	1.36	28.92	159	16
0:18:02	17.31	2.37	36.47	1.26	1.44	30.74	161	
0:18:33	17.38	2.35	34.8	1.39	1.35	28.67	162	
0:19:04	17.33	2.38	36.12	1.29	1.42	30.25	163	
0:19:35	17.23	2.41	36.5	1.4	1.48	31.46	163	18
0:20:06	17.31	2.38	40.57	1.35	1.61	34.19	163	
0:20:36	17.48	2.32	37.43	1.21	1.4	29.89	162	
0:21:07	17.35	2.38	39.04	1.63	1.53	32.46	164	
0:21:38	17.4	2.37	41.67	1.34	1.6	34.06	164	18
0:22:08	17.53	2.32	30.42	0.63	1.12	23.87		

Table 43. Subject 145 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:35	18.03	2.28	20.24	0.61	0.62	6.75		
0:01:06	17.5	2.54	24.75	0.69	0.91	9.89	97	
0:01:37	17.21	2.59	28.4	0.92	1.15	12.45		7
0:02:08	17.3	2.41	26.72	0.76	1.06	11.52	90	
0:02:39	17.25	2.39	26.29	0.97	1.06	11.5		
0:03:10	17.17	2.41	24.22	0.67	1	10.87	90	
0:03:41	17.17	2.39	25.58	0.78	1.06	11.48		
0:04:12	17.09	2.38	23.17	0.58	0.98	10.68	95	7
0:04:42	17.06	2.36	24.91	1	1.07	11.59		
0:05:12	16.99	2.37	24.41	0.76	1.07	11.59	92	
0:05:43	17.07	2.36	25.04	0.86	1.07	11.6		
0:06:14	17.16	2.34	23.03	0.72	0.96	10.39	90	
0:06:45	17.02	2.4	28.87	0.9	1.25	13.53	98	7
0:07:16	17.28	2.37	22.82	0.56	0.91	9.9		
0:07:47	16.92	2.48	26.38	0.75	1.17	12.67		
0:08:18	16.8	2.48	25.16	0.68	1.15	12.5	99	
0:08:48	16.62	2.5	28.65	1.06	1.37	14.94		7
0:09:20	16.84	2.47	29.74	0.9	1.35	14.63	100	
0:09:50	17.01	2.45	28.34	0.91	1.22	13.31		
0:10:20	16.97	2.46	28.08	1.04	1.23	13.34	100	
0:10:51	17	2.46	27.69	1.07	1.2	13.01		
0:11:22	16.76	2.49	27.14	0.97	1.26	13.65	96	7
0:11:53	16.89	2.51	29.7	0.99	1.32	14.38		
0:12:24	16.99	2.43	29.35	0.89	1.28	13.87	95	
0:12:55	17.13	2.39	24.05	0.83	1.01	10.93		
0:13:26	16.62	2.47	27.6	0.75	1.33	14.43	103	7
0:13:56	16.69	2.47	34.13	1.07	1.61	17.51		
0:14:28	17.37	2.33	35.02	1.09	1.36	14.8	109	
0:14:58	17.16	2.38	34.08	1.03	1.41	15.34		
0:15:28	16.48	2.52	36.36	0.91	1.81	19.65	105	
0:15:59	16.5	2.53	36.44	1.21	1.8	19.59		
0:16:30	16.54	2.53	36.42	1.1	1.78	19.33	109	8
0:17:01	16.57	2.53	38.84	1.21	1.88	20.47		
0:17:32	16.7	2.52	36.11	1.16	1.7	18.43	105	
0:18:03	16.6	2.56	37.07	0.86	1.78	19.38		
0:18:34	16.75	2.49	40.98	1.11	1.9	20.64	99	
0:19:05	16.95	2.4	37.12	1.24	1.64	17.79		
0:19:35	16.63	2.43	35.98	1.2	1.73	18.78	109	
0:20:06	16.49	2.47	40.76	1.31	2.03	22.02		
0:20:37	16.71	2.44	37.57	1.02	1.77	19.2	107	8
0:21:07	16.58	2.47	38.2	1.12	1.86	20.17		
0:21:38	16.72	2.46	41.36	1.38	1.93	21.03		
0:22:09	16.68	2.46	45.56	1.42	2.16	23.43	121	
0:22:40	16.43	2.54	49.34	1.5	2.48	26.93		
0:23:11	16.61	2.51	53.78	1.54	2.59	28.11	131	
0:23:42	16.77	2.5	56.52	1.66	2.6	28.3		9

Table 43. Subject 145 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:13	16.94	2.45	60.7	1.6	2.68	29.11	133	
0:24:43	16.86	2.42	59.44	1.52	2.69	29.2		
0:25:14	16.86	2.44	60.22	1.67	2.72	29.53	132	
0:25:44	17.01	2.39	57.85	1.38	2.51	27.23		9
0:26:15	16.6	2.47	61.47	1.71	2.97	32.27	137	
0:26:46	16.86	2.41	61.38	1.66	2.77	30.15		
0:27:17	17.08	2.32	61.62	1.62	2.63	28.59	135	
0:27:48	16.94	2.32	59.34	1.52	2.63	28.61	138	9
0:28:19	16.9	2.35	67.45	1.53	3.02	32.83		
0:28:50	17.08	2.37	65.01	1.63	2.76	30.03		
0:29:20	17.02	2.39	72.36	1.72	3.12	33.94	147	
0:29:50	17.09	2.37	79.21	1.84	3.36	36.52		
0:30:22	17.16	2.33	82.42	2.01	3.43	37.29	158	
0:30:52	17.3	2.31	91.36	1.99	3.64	39.58		11
0:31:23	17.41	2.27	89.71	1.99	3.46	37.61	159	
0:31:54	17.38	2.32	88.21	2.1	3.42	37.22		
0:32:25	17.32	2.32	90.67	1.93	3.59	39.03	160	
0:32:56	17.43	2.27	95.07	2.02	3.65	39.67		11
0:33:26	17.52	2.22	95.04	1.98	3.55	38.59	163	
0:33:58	17.53	2.18	97.5	2.12	3.64	39.6		
0:34:28	17.65	2.13	102.7	2.14	3.69	40.13	162	
0:34:59	17.53	2.13	103.4	2.03	3.87	42.1	164	11
0:35:30	17.53	2.13	93.41	1.87	3.5	38.01		

Table 44. Subject 173 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:37	17.92	2.34	18.09	0.57	0.58	8.9		
0:01:08	17.49	2.45	19.86	0.83	0.74	11.35	89	
0:01:38	17.1	2.53	19.52	0.59	0.82	12.56		
0:02:09	16.87	2.61	19.48	0.63	0.87	13.34	90	7
0:02:40	16.82	2.61	19.46	0.67	0.88	13.52		
0:03:11	16.89	2.59	21.18	0.64	0.94	14.42	84	
0:03:42	16.81	2.58	18.97	0.63	0.86	13.21		
0:04:13	16.87	2.59	19.98	0.71	0.89	13.71	88	8
0:04:43	16.85	2.61	19.16	0.83	0.86	13.21		
0:05:13	16.87	2.63	21.4	0.86	0.95	14.64	90	
0:05:45	16.97	2.63	17.85	0.62	0.77	11.86		8
0:06:16	16.72	2.76	17.48	0.76	0.8	12.38	91	
0:06:47	16.81	2.73	20.86	0.67	0.94	14.44		
0:07:18	16.98	2.61	25.65	0.88	1.11	17.04		
0:07:48	17.06	2.61	27.28	1.01	1.15	17.69	99	
0:08:19	16.99	2.65	25.48	1.34	1.09	16.8		
0:08:49	16.8	2.76	23.72	1.19	1.07	16.41	98	12
0:09:20	16.62	2.85	22.13	0.96	1.04	16.04		
0:09:51	16.55	2.86	25.05	0.89	1.2	18.44	104	
0:10:22	16.56	2.83	25.95	1.37	1.24	19.12		
0:10:53	16.69	2.82	24.76	1.18	1.15	17.63	103	12
0:11:24	16.7	2.83	25.72	0.95	1.18	18.22		
0:11:55	16.72	2.8	23.77	1.03	1.09	16.8	98	
0:12:26	16.69	2.84	23.59	1.31	1.09	16.78		
0:12:57	16.58	2.86	23.4	0.78	1.11	17.09	104	
0:13:27	16.37	2.94	27.81	1.32	1.39	21.36	103	12
0:13:57	16.79	2.83	26.04	1.18	1.17	18.03		
0:14:28	16.72	2.73	27.27	1.24	1.26	19.33		
0:14:59	16.66	2.78	28.26	1.41	1.32	20.34	109	
0:15:30	16.54	2.84	29.82	1.66	1.43	22.05		
0:16:01	16.68	2.81	30.45	1.69	1.41	21.72	111	13
0:16:32	16.57	2.86	29.52	1.34	1.41	21.65		
0:17:02	16.56	2.86	27.82	1.46	1.33	20.48	109	
0:17:33	16.44	2.87	28.53	1.43	1.41	21.65	117	
0:18:04	16.45	2.86	30.83	1.71	1.52	23.32		13
0:18:35	16.57	2.82	28.94	1.03	1.38	21.24	115	
0:19:06	16.5	2.84	29.09	1.21	1.42	21.77	113	
0:19:37	16.32	2.91	30.87	1.62	1.56	24.06	113	
0:20:07	16.6	2.85	30.17	1.16	1.43	21.95	117	13
0:20:38	16.52	2.85	31.22	1.16	1.51	23.19		
0:21:09	16.64	2.78	27.33	1.24	1.28	19.76		
0:21:40	16.9	2.74	21.85	0.91	0.96	14.72		
0:22:11	16.87	2.77	17.75	0.55	0.78	12.04		
0:22:41	17.27	2.56	14.97	0.58	0.59	9.11		
0:23:12	17.41	2.49	13.3	0.38	0.51	7.77		
0:23:43	17.54	2.45	17.18	0.51	0.63	9.65		

Table 44. Subject 173 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:14	17.64	2.38	11.58	0.28	0.41	6.3		
0:24:44	17.59	2.4	12.2	0.39	0.44	6.76		
0:25:15	17.47	2.42	16.37	0.63	0.61	9.43		
0:25:46	17.77	2.37	20.19	0.42	0.68	10.49		
0:26:17	17.9	2.41	24.27	0.87	0.78	11.97		
0:26:48	17.05	2.64	27.49	0.72	1.16	17.81	124	
0:27:18	16.46	2.75	37.88	1.31	1.87	28.74	128	

Table 45. Subject 214 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.29	2.55	23.47	0.94	0.92	11.97		
0:01:07	16.89	2.78	26.96	1	1.18	15.32	100	
0:01:38	16.49	2.96	27.3	1.14	1.32	17.13		
0:02:09	16.4	2.95	23.89	0.77	1.18	15.34	90	6
0:02:39	16.22	2.99	29.05	1.08	1.5	19.49		
0:03:10	16.6	2.92	25.44	0.85	1.2	15.56	91	
0:03:41	16.44	2.94	23.61	0.79	1.16	15.03		
0:04:12	16.18	3.01	26.35	1.15	1.38	17.84	94	
0:04:43	16.28	3.01	26.44	0.98	1.35	17.48		
0:05:13	16.49	2.93	25.74	1.12	1.25	16.17	92	
0:05:43	16.41	2.96	25.23	1.15	1.25	16.18		
0:06:14	16.41	2.96	27.17	1.18	1.34	17.41	98	6
0:06:46	16.6	2.91	27.3	1.05	1.29	16.68		
0:07:17	16.53	2.98	32.06	1.23	1.53	19.9		
0:07:46	16.52	3.02	29.71	0.93	1.42	18.44		
0:08:17	15.97	3.12	31.68	1.44	1.73	22.42	107	
0:08:48	16.02	3.13	31.77	1.32	1.71	22.22		7
0:09:20	16.11	3.11	37.25	1.62	1.97	25.5	106	
0:09:51	16.55	2.98	32.85	1.17	1.56	20.25		
0:10:20	16.18	3.09	34.26	1.63	1.78	23.12	113	
0:10:51	16.34	3.07	35.17	1.26	1.76	22.83		7
0:11:22	16.49	3.05	33.91	1.3	1.63	21.16	113	
0:11:54	16.39	3.09	36.7	1.05	1.81	23.51		
0:12:25	16.44	3.01	31.48	0.95	1.54	19.97	109	
0:12:55	16.34	3.03	35.39	1.31	1.77	22.97		
0:13:25	16.33	3.11	35.03	1.67	1.75	22.73	118	8
0:13:56	16.43	3.1	35.6	1.48	1.74	22.51		
0:14:27	16.67	3.02	36.49	1.4	1.68	21.78	112	
0:14:58	16.51	3.07	38.2	1.47	1.83	23.69		
0:15:29	16.51	3	38.36	1.48	1.84	23.89	122	
0:15:59	16.3	3.1	40.08	1.6	2.02	26.18		9
0:16:30	16.58	3.04	40.62	1.5	1.91	24.77	113	
0:17:01	16.55	3.02	38.47	1.48	1.82	23.66		
0:17:32	16.52	3.02	40.43	1.44	1.93	25.06	119	
0:18:03	16.51	3.03	37.83	1.51	1.82	23.54		9
0:18:33	16.34	3.13	39.73	1.47	1.98	25.71	119	
0:19:04	16.44	3.09	39.31	1.51	1.91	24.81		
0:19:35	16.43	3.09	39.14	1.4	1.91	24.78	116	
0:20:07	16.41	3.07	39.71	1.47	1.95	25.28	126	9
0:20:37	16.62	3.03	40.59	1.5	1.89	24.55		
0:21:07	16.65	3.01	33.06	1.5	1.53	19.82		
0:21:38	16.91	2.93	25.06	0.52	1.08	14.02		
0:22:09	17.15	2.79	19.29	0.54	0.78	10.13		
0:22:40	17.4	2.69	14.27	0.45	0.54	6.96		
0:23:11	17.29	2.63	13	0.32	0.51	6.61		
0:23:42	17.21	2.58	18.08	0.62	0.73	9.46		

Table 45. Subject 214 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:12	17.21	2.59	20.71	0.61	0.83	10.83		
0:24:43	17.32	2.67	27.93	0.93	1.08	14		
0:25:15	16.84	2.95	36.09	1.44	1.59	20.56		
0:25:45	16.29	3.08	38.08	1.52	1.93	24.98		
0:26:16	16.04	3.13	46.68	1.67	2.5	32.45	135	
0:26:46	16.2	3.11	45.42	1.82	2.35	30.45		
0:27:17	15.89	3.32	46.68	2.03	2.57	33.33	139	
0:27:49	15.92	3.38	47.28	2.25	2.58	33.43		12
0:28:19	16	3.42	50.95	2.04	2.72	35.28	138	
0:28:49	16.2	3.36	50.29	2.1	2.57	33.31		
0:29:20	16.34	3.27	51.63	2.07	2.55	33.09	141	
0:29:51	16.28	3.26	53.12	2.12	2.67	34.65		12
0:30:23	16.31	3.26	52.18	2.17	2.61	33.79	144	
0:30:53	16.33	3.25	53.44	2.23	2.65	34.4		
0:31:23	16.29	3.24	53.74	2.07	2.69	34.95	146	
0:31:54	16.45	3.17	53.81	2.24	2.6	33.71	147	12
0:32:25	16.24	3.28	53.75	2.15	2.72	35.32		
0:32:56	16.54	3.15	45.17	1.88	2.13	27.67		
0:33:26	16.75	3.12	33.24	0.81	1.48	19.25		
0:33:57	17.69	2.86	29.08	1.38	0.97	12.64		
0:34:28	18.34	2.52	22.7	0.42	0.59	7.7		
0:35:00	18.19	2.45	18.33	0.48	0.52	6.71		
0:35:31	17.96	2.46	17.56	0.53	0.55	7.08		
0:36:01	17.91	2.39	15.17	0.33	0.48	6.29		
0:36:31	17.71	2.41	24.5	0.61	0.84	10.94		
0:37:02	17.49	2.65	33.6	1.29	1.23	15.96		
0:37:33	16.78	2.98	41.73	1.3	1.86	24.19		
0:38:05	16.06	3.02	49.08	1.89	2.63	34.16		
0:38:34	16	3.11	60.23	2.23	3.26	42.31	158	
0:39:05	16.1	3.23	63.02	2.42	3.31	42.98		
0:39:36	16.39	3.26	68.99	2.65	3.37	43.73	167	15
0:40:07	16.26	3.4	70.61	2.72	3.54	45.96		
0:40:38	16.63	3.26	77.31	2.97	3.54	45.98	169	
0:41:08	16.66	3.27	75.46	2.79	3.43	44.46		
0:41:39	16.73	3.21	77.78	2.88	3.48	45.11	172	15
0:42:09	16.78	3.17	76.85	2.74	3.39	44.02		
0:42:41	16.86	3.08	80.94	2.89	3.52	45.62	173	
0:43:12	16.8	3.08	74.7	2.58	3.3	42.82		
0:43:42	16.56	3.21	78.58	2.81	3.68	47.79	73	15
0:44:13	16.87	3.07	83.66	2.61	3.62	46.97	169	
0:44:44	16.91	3.02	73.89	2.05	3.17	41.15		

Table 46. Subject 221 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.27	2.55	18.82	0.34	0.75	9.95		
0:01:06	16.77	2.65	21.36	0.76	0.98	13.02	102	
0:01:38	15.95	2.79	22.29	1.01	1.24	16.56		
0:02:08	15.77	2.84	21.69	1.2	1.25	16.72	99	10
0:02:39	15.71	2.86	21.98	0.69	1.29	17.16		
0:03:09	15.81	2.85	20.63	0.9	1.18	15.76	105	
0:03:40	15.77	2.88	22.49	0.7	1.3	17.32		
0:04:11	15.63	2.9	21.87	0.52	1.3	17.33	98	11
0:04:42	15.76	2.9	20.56	0.57	1.19	15.84		
0:05:13	15.85	2.89	21.28	0.82	1.21	16.09	101	
0:05:43	15.76	2.93	21.56	0.86	1.24	16.59		11
0:06:14	15.53	2.98	20.21	0.58	1.22	16.3	98	
0:06:45	15.7	3	23.12	0.72	1.35	17.95		
0:07:16	15.76	2.98	25.55	0.61	1.47	19.63	115	
0:07:46	15.47	3.08	27.85	0.96	1.7	22.64		
0:08:17	14.96	3.24	31.04	1.03	2.08	27.75	123	
0:08:48	14.93	3.31	31.89	1.33	2.14	28.56		12
0:09:19	15.17	3.27	30.51	1.17	1.96	26.15	123	
0:09:50	15.12	3.29	34.8	1.66	2.26	30.08		
0:10:21	15.5	3.2	33.82	1.35	2.04	27.16	125	
0:10:52	15.47	3.21	32.88	1.49	2	26.6		12
0:11:22	15.35	3.29	33.33	1.39	2.07	27.56	127	
0:11:53	15.35	3.29	34.45	1.23	2.13	28.46		
0:12:25	15.57	3.25	34.71	1.65	2.06	27.4	126	
0:12:55	15.51	3.28	34.29	1.49	2.05	27.39	124	12
0:13:25	15.47	3.25	33.66	1.25	2.04	27.17		
0:13:56	15.48	3.23	38.38	1.83	2.32	30.96	141	
0:14:27	15.39	3.28	38.42	1.92	2.36	31.49		
0:14:58	15.31	3.39	38.4	1.75	2.39	31.88	148	
0:15:30	15.32	3.36	41.16	1.71	2.56	34.09		13
0:16:00	15.33	3.42	41.87	2.09	2.59	34.56	144	
0:16:30	15.43	3.39	40.63	2.03	2.46	32.86		
0:17:01	15.44	3.37	40.19	1.91	2.43	32.44	145	
0:17:32	15.41	3.4	41.99	2.1	2.56	34.12		13
0:18:03	15.5	3.33	42.83	2.04	2.57	34.26	148	
0:18:33	15.54	3.3	41.92	2.1	2.49	33.25		
0:19:04	15.5	3.32	43.55	1.81	2.61	34.84	153	
0:19:35	15.47	3.32	41.48	1.73	2.5	33.37	151	13
0:20:06	15.42	3.33	45.19	1.96	2.76	36.74		
0:20:36	15.7	3.21	37.25	1.77	2.15	28.69		
0:21:08	15.97	3.17	36.35	1.45	1.98	26.36		
0:21:39	16.4	3.06	33.85	1.54	1.67	22.26		
0:22:09	16.65	2.95	31	1.11	1.44	19.2		
0:22:40	16.82	2.79	23.15	1.01	1.03	13.79		
0:23:11	16.96	2.68	23.6	1.03	1.02	13.6		
0:23:41	16.81	2.66	22.94	0.96	1.04	13.81		

Table 46. Subject 221 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:12	16.64	2.63	23.89	0.65	1.13	15.08		
0:24:43	16.22	2.7	20.9	0.84	1.1	14.62		
0:25:14	16.09	2.7	17.92	0.66	0.97	12.95		
0:25:44	16.45	2.62	15.66	0.31	0.78	10.4		
0:26:16	16.76	2.54	15.03	0.26	0.69	9.24		
0:26:47	16.89	2.5	15.41	0.3	0.69	9.16		
0:27:17	17.04	2.49	15.59	0.32	0.67	8.87		
0:27:47	17.15	2.5	14.12	0.29	0.58	7.78		
0:28:18	17.12	2.53	15.07	0.37	0.63	8.36		
0:28:49	17.28	2.47	12.49	0.36	0.49	6.6		
0:29:20	17.26	2.5	12.58	0.31	0.5	6.7		
0:29:51	17.14	2.52	18.86	0.48	0.78	10.41		
0:30:22	17.45	2.38	20.02	0.26	0.76	10.1		
0:30:52	17.58	2.29	21.75	0.46	0.79	10.56		
0:31:23	16.24	2.64	26.55	0.78	1.39	18.54		
0:31:54	15.22	2.83	30.76	0.85	1.99	26.58		
0:32:25	14.79	3.04	37.27	1.49	2.6	34.64	171	
0:32:56	14.63	3.25	52.15	2.17	3.71	49.49		
0:33:27	15.59	3.18	61.64	2.05	3.65	48.72	177	
0:33:57	16.05	3.11	71.09	2.15	3.8	50.72		
0:34:28	16.37	3.07	69.83	2.12	3.46	46.19	182	
0:34:59	16.37	3.06	74.87	2.14	3.72	49.58		
0:35:30	16.51	2.98	71.54	2.1	3.44	45.84	185	
0:36:00	16.44	2.97	72.83	2.14	3.57	47.63		
0:36:31	16.45	2.97	74.93	2.08	3.67	48.89	186	
0:37:02	16.5	2.91	71.47	2.1	3.46	46.17		
0:37:33	16.45	2.92	77.86	2.1	3.81	50.82	185	
0:38:03	16.61	2.83	80.06	2.05	3.78	50.36		
0:38:34	16.68	2.77	73.73	1.94	3.43	45.67		
0:00:35	15.22	2.85	35.6	1.19	2.31	30.74		
0:01:06	14.91	3	56.11	1.81	3.83	51.08	188	
0:01:36	15.79	2.85	73.82	2	4.25	56.64		
0:02:08	16.52	2.81	86.84	2.17	4.21	56.1	192	
0:02:39	16.83	2.83	88.65	2.22	3.94	52.48		18
0:03:09	16.81	2.88	90.74	2.33	4.04	53.88	196	
0:03:40	16.83	2.89	92.37	2.37	4.09	54.55		
0:04:11	16.88	2.88	95.56	2.39	4.17	55.62	199	
0:04:42	16.94	2.86	95.06	2.21	4.08	54.44		20
0:05:12	17	2.8	99.92	2.13	4.23	56.38	201	
0:05:43	17.07	2.74	97.44	1.91	4.05	54.06		
0:06:14	17.07	2.72	96.13	1.75	4.01	53.49	206	
0:06:45	17	2.71	95.44	1.84	4.06	54.16		20
0:07:16	16.84	2.76	29.39	0.53	1.31	17.46		

Table 47. Subject 224 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.24	2.32	14.37	0.33	0.58	9.73		
0:01:08	16.28	2.66	13.94	0.32	0.72	12.05	96	
0:01:38	15.77	2.83	14.96	0.37	0.87	14.43		
0:02:09	15.39	2.9	13.87	0.28	0.87	14.43	101	6
0:02:40	15.27	2.98	17.14	0.55	1.09	18.22		
0:03:10	15.5	2.95	16.12	0.39	0.98	16.37	91	
0:03:42	15.85	2.88	17.18	0.51	0.97	16.23		
0:04:12	16.21	2.82	16.64	0.39	0.87	14.5	91	6
0:04:42	16.22	2.88	17.05	0.4	0.89	14.79		
0:05:14	16.31	2.87	16.85	0.48	0.86	14.31	94	
0:05:44	16.58	2.77	18.76	0.57	0.9	14.92		
0:06:15	16.59	2.77	17.58	0.53	0.84	13.95	99	7
0:06:46	16.64	2.78	17.95	0.51	0.84	14.06		
0:07:16	16.33	2.85	20.87	0.43	1.06	17.66		
0:07:48	16.51	2.82	20.92	0.65	1.01	16.9		
0:08:18	16.52	2.83	20.74	0.56	1	16.7	104	
0:08:49	16.21	2.87	17.51	0.36	0.91	15.23		
0:09:20	15.75	2.95	20.33	0.51	1.17	19.58	111	
0:09:51	16.34	2.9	17.38	0.46	0.88	14.61		8
0:10:22	16.04	2.99	21.04	0.64	1.14	18.93	104	
0:10:52	16.48	2.9	19.45	0.57	0.95	15.8		
0:11:23	16.33	2.96	18.96	0.47	0.95	15.92	108	
0:11:55	16.21	2.99	22.61	0.75	1.17	19.55		11
0:12:25	16.39	2.97	22.6	0.71	1.12	18.72	109	
0:12:56	16.54	2.91	23.69	0.7	1.14	18.92		
0:13:27	16.7	2.85	19.19	0.39	0.88	14.73	107	
0:13:57	16.46	2.94	19.9	0.41	0.97	16.18		11
0:14:29	16.24	2.97	20.74	0.52	1.07	17.79		
0:14:59	16.16	2.96	26.77	0.79	1.41	23.48		
0:15:30	16.67	2.84	27.15	0.78	1.26	20.99	126	
0:16:01	16.39	2.96	26.66	0.72	1.32	22.08		
0:16:31	16.24	3.04	28.9	0.72	1.49	24.76	131	13
0:17:03	16.3	3.04	26.54	0.68	1.34	22.4		
0:17:33	16.15	3.12	27.47	0.62	1.44	23.96	128	
0:18:04	16.12	3.11	30.57	0.69	1.61	26.83		
0:18:35	16.47	2.98	33.32	0.98	1.62	26.99	130	15
0:19:05	16.66	2.92	29.22	0.77	1.35	22.56		
0:19:37	16.34	3.03	33.34	0.85	1.67	27.85	132	
0:20:07	16.56	2.92	30.99	0.77	1.47	24.56		
0:20:38	16.5	2.93	29.25	0.75	1.41	23.56	131	12
0:21:09	16.29	2.98	30.56	0.73	1.55	25.88		
0:21:39	16.4	2.92	30.54	0.68	1.51	25.24		
0:22:11	17.09	2.67	28.31	0.83	1.18	19.64		
0:22:41	17.87	2.41	20.13	0.32	0.65	10.87		
0:23:12	17.79	2.4	16.13	0.6	0.54	8.98		
0:23:43	17.81	2.36	15.18	0.31	0.5	8.41		

Table 47. Subject 224 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:14	17.8	2.35	15.13	0.5	0.51	8.44		
0:24:46	17.55	2.48	15.07	0.29	0.55	9.11		
0:25:15	17.96	2.4	21.25	0.59	0.66	11.07		
0:25:47	17.96	2.41	27.06	0.6	0.85	14.09		
0:26:18	16.92	2.6	28.13	0.78	1.24	20.61		
0:26:48	16.22	2.69	35.4	0.86	1.86	31.02		
0:27:20	16.15	2.89	40.59	1.01	2.15	35.76		
0:27:50	16.35	3.16	44.51	1.11	2.21	36.79		
0:28:21	16.53	3.29	48.67	1.16	2.29	38.16		
0:28:51	16.75	3.3	48.15	1.15	2.13	35.45		
0:29:21	16.79	3.3	49.31	1.1	2.15	35.9		
0:29:53	16.73	3.35	49.94	1.22	2.22	36.93		
0:30:24	16.74	3.3	45.48	0.69	2.02	33.65		
0:30:55	16.26	3.48	46.61	0.79	2.33	38.81		
0:31:25	16.48	3.4	18.11	0.37	0.86	14.31		
0:31:55	17.07	3.09	12.98	0.21	0.53	8.81		
0:00:36	16.62	2.36	29.13	0.73	1.41	23.49		
0:01:08	16.46	2.41	31.06	0.65	1.56	25.99		
0:01:38	15.97	2.51	35.7	1.08	2	33.4		
0:02:09	16.54	2.53	38.06	1.06	1.86	31.06	152	
0:02:40	16.47	2.67	41.59	1.09	2.05	34.23		
0:03:10	16.31	2.78	45.81	1.27	2.34	39.02	167	
0:03:42	16.27	2.96	46.48	1.26	2.38	39.66		
0:04:11	16.22	3.08	49.67	1.42	2.56	42.67	177	15
0:04:43	16.37	3.06	49.04	1.49	2.43	40.58		
0:05:13	16.25	3.13	51.58	1.36	2.63	43.82	183	
0:05:44	16.5	3.03	52.09	1.13	2.51	41.8		
0:06:15	16.43	3.04	57.77	1.41	2.83	47.16	186	19
0:06:46	16.65	2.97	57.54	1.25	2.66	44.39		
0:07:17	16.72	2.93	59.98	1.28	2.73	45.54	190	
0:07:47	16.78	2.89	56.64	1.29	2.55	42.42		
0:08:18	16.68	2.88	56.8	1.26	2.62	43.69	190	20
0:08:48	16.73	2.85	58.04	1.29	2.65	44.22		
0:09:20	16.73	2.82	26.68	0.49	1.22	20.31		
0:09:50	16.76	2.8	15.99	0.4	0.73	12.1		
0:10:21	16.77	2.79	18.24	0.44	0.83	13.76		

Table 48. Subject 230 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	18.08	2.29	16.86	0.4	0.51	7.99	82	
0:01:06	17.74	2.49	17.66	0.41	0.6	9.42	86	
0:01:37	17.02	2.64	17.52	0.49	0.75	11.75		6
0:02:08	16.7	2.62	19.82	0.62	0.92	14.57		
0:02:39	16.59	2.59	20.41	0.66	0.98	15.48		
0:03:10	16.67	2.59	19.98	0.62	0.94	14.82	93	6
0:03:41	16.72	2.62	19.16	0.58	0.89	14		
0:04:11	16.83	2.61	21.36	0.65	0.96	15.13		
0:04:42	16.94	2.58	19.57	0.61	0.86	13.48		
0:05:13	16.92	2.65	16.98	0.41	0.74	11.72	94	6
0:05:43	16.81	2.72	22.28	0.59	1	15.78		
0:06:14	16.73	2.74	21.56	0.6	0.99	15.59		
0:06:45	16.97	2.67	21.05	0.73	0.91	14.28	107	
0:07:16	16.91	2.72	22.14	0.71	0.97	15.24		
0:07:47	17.01	2.72	23.59	0.71	1	15.78		
0:08:18	16.65	2.81	22.64	0.5	1.06	16.67	105	9
0:08:48	16.59	2.77	24.07	0.75	1.15	18.06	106	
0:09:19	16.61	2.71	23.44	0.76	1.11	17.55	104	
0:09:50	16.42	2.79	23.88	0.72	1.19	18.68	104	
0:10:21	16.6	2.79	23.81	0.74	1.13	17.79	109	8
0:10:51	16.66	2.79	24.61	0.77	1.15	18.09	107	
0:11:22	16.66	2.81	24.78	0.73	1.15	18.19		
0:11:53	16.72	2.83	20.26	0.53	0.93	14.62		
0:12:24	16.7	2.85	4.36	0.14	0.2	3.16		
0:00:36	19.55	1.01	8.44	0.19	0.12	1.97		
0:01:06	18.88	1.34	7.78	0.14	0.17	2.74		
0:01:38	18.17	1.7	5.94	0.07	0.18	2.85		
0:02:09	18.4	1.61	7.02	0.09	0.2	3.07	98	
0:02:39	18.22	1.69	16.68	0.33	0.5	7.85		
0:03:10	17.73	2.14	18.76	0.43	0.65	10.3	95	
0:03:41	17.15	2.4	21.53	0.62	0.89	14.08		9
0:04:11	16.54	2.55	22.51	0.59	1.1	17.3	99	
0:04:42	16.4	2.6	23.71	0.79	1.2	18.85		
0:05:14	16.46	2.63	23.51	0.71	1.17	18.41	101	
0:05:44	16.36	2.69	23.31	0.78	1.18	18.61		9
0:06:14	16.6	2.68	23.02	0.68	1.1	17.29	97	
0:06:45	16.5	2.72	24.78	0.73	1.21	19.09		
0:07:16	16.62	2.7	23.19	0.66	1.1	17.33	100	
0:07:47	16.67	2.71	24.34	0.81	1.14	17.92	101	9
0:08:18	16.63	2.75	24.95	0.66	1.18	18.53		
0:08:48	16.82	2.71	25.01	0.83	1.12	17.68		108
0:09:19	16.92	2.67	25.73	0.76	1.13	17.73		
0:09:50	16.94	2.66	26.28	0.88	1.14	17.99		112
0:10:21	16.79	2.75	28.31	0.88	1.28	20.11		
0:10:51	16.69	2.79	29.73	0.96	1.38	21.67		

Table 48. Subject 230 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:11:22	16.62	2.84	30.01	1	1.41	22.23		10
0:11:53	16.74	2.82	30.1	0.75	1.37	21.6	111	
0:12:24	16.64	2.83	31.38	0.92	1.47	23.14		
0:12:54	16.71	2.84	30.83	1.03	1.42	22.3	117	
0:13:25	16.82	2.8	30.9	0.94	1.38	21.72		11
0:13:56	16.76	2.79	30.91	1.07	1.4	22.09	188	
0:14:26	16.74	2.78	30.03	0.83	1.37	21.61		
0:14:57	16.71	2.85	30.45	0.92	1.4	22.04	115	
0:15:28	16.79	2.85	31.16	0.92	1.4	22.05	115	10
0:15:58	16.79	2.81	30.52	0.87	1.37	21.61		

Table 49. Subject 231 condition A.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:35	17.18	1.95	13.08	0.35	0.55	8.97		
0:01:07	17.33	1.9	14.14	0.46	0.57	9.29	80	
0:01:38	17.14	1.99	14.67	0.41	0.63	10.15		
0:02:09	17.21	1.96	13.87	0.46	0.58	9.44	86	6
0:02:39	17.24	1.94	14.68	0.41	0.61	9.89		
0:03:10	17.12	1.98	14.75	0.42	0.63	10.29	89	
0:03:40	17.12	1.95	14.21	0.39	0.61	9.93		
0:04:11	17.07	1.98	15.46	0.5	0.68	10.94	89	6
0:04:42	17.2	1.95	14.7	0.57	0.62	10.03		
0:05:13	17.39	1.88	15.16	0.35	0.6	9.79	89	
0:05:43	17.3	1.92	14.45	0.45	0.59	9.57	81	
0:06:14	17.21	1.91	15.29	0.51	0.64	10.43		7
0:06:45	17.33	1.89	13.56	0.45	0.55	8.92		
0:07:16	17.34	1.91	14.96	0.31	0.61	9.82		
0:07:46	17.43	1.84	15.79	0.3	0.62	10.11		
0:08:18	17.36	1.86	16.93	0.48	0.68	11.07	94	
0:08:48	17.36	1.88	18.79	0.48	0.76	12.24		
0:09:18	16.92	2.02	19.99	0.5	0.91	14.74	85	
0:09:49	16.81	2.03	20.33	0.5	0.95	15.43		7
0:10:20	16.71	2.1	20.8	0.59	1	16.14	90	
0:10:51	16.87	2.07	20.94	0.72	0.96	15.61		
0:11:22	16.88	2.08	19.38	0.46	0.89	14.36	80	
0:11:53	16.97	2.08	20.17	0.59	0.9	14.58		7
0:12:24	16.91	2.09	20.38	0.58	0.92	14.99	88	
0:12:54	16.91	2.08	19.5	0.78	0.89	14.34		
0:13:25	16.93	2.07	19.76	0.58	0.89	14.47	90	
0:13:56	16.95	2.08	18.95	0.68	0.85	13.8	85	7
0:14:26	16.88	2.1	20.02	0.47	0.92	14.86		
0:14:57	16.84	2.11	21.23	0.61	0.98	15.88	96	
0:15:28	16.83	2.11	22.12	0.76	1.02	16.59		
0:15:59	16.82	2.16	23.56	0.74	1.09	17.68	98	
0:16:30	16.9	2.17	22.19	0.67	1.01	16.3		9
0:17:01	16.87	2.17	22.66	0.73	1.04	16.79	93	
0:17:31	16.82	2.16	22.52	0.64	1.04	16.92		
0:18:02	16.78	2.18	22.99	0.72	1.07	17.42	94	
0:18:33	16.81	2.2	24.12	0.69	1.12	18.14		9
0:19:03	16.85	2.18	24.2	0.67	1.11	18.03	98	
0:19:34	16.94	2.16	24.2	0.6	1.08	17.58		
0:20:05	16.84	2.16	23.54	0.78	1.08	17.57	95	
0:20:35	16.81	2.16	23.79	0.72	1.11	17.92	96	9
0:00:35	17.03	2.1	15.21	0.66	0.67	10.81		
0:01:07	17.29	2.02	12.87	0.3	0.52	8.5		
0:01:38	17.38	2.1	12.3	0.34	0.48	7.86		
0:02:08	17.43	2.01	11.99	0.43	0.47	7.58		
0:02:39	17.47	1.99	13.63	0.34	0.53	8.52		

Table 49. Subject 231 condition A (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:03:09	17.52	1.98	16.52	0.37	0.63	10.17		
0:03:40	17.5	1.98	20.54	0.45	0.79	12.74		
0:04:11	16.94	2.11	23.86	0.66	1.07	17.36		
0:04:42	16.37	2.23	27.64	0.84	1.43	23.2	112	
0:05:13	16.26	2.28	28.94	0.76	1.54	24.89		
0:05:43	16.27	2.31	30.52	0.78	1.62	26.19	114	
0:06:15	16.3	2.34	30.09	0.86	1.58	25.56		11
0:06:45	16.31	2.37	33.06	0.81	1.73	27.97	121	
0:07:15	16.47	2.36	31.8	0.91	1.6	25.89		
0:07:47	16.51	2.37	32.42	0.85	1.61	26.14	117	
0:08:17	16.61	2.36	31.91	0.69	1.55	25.09		12
0:08:47	16.47	2.42	35.6	1.05	1.78	28.88	123	
0:09:19	16.68	2.34	33.42	0.74	1.59	25.82		
0:09:49	16.71	2.31	32.63	0.91	1.54	25.03	121	
0:10:20	16.74	2.32	34.36	1.07	1.61	26.15	123	12
0:10:51	16.76	2.3	32.93	0.87	1.54	24.93		
0:11:23	16.78	2.25	24.47	0.68	1.14	18.48		
0:00:36	19.4	0.87	3.21	0.1	0.06	0.89		
0:01:07	20.49	0.21	3.81	0.14	0.02	0.31		
0:01:38	20.63	0.08	5.06	0.24	0.02	0.3		
0:02:08	20.36	0.21	11.31	0.31	0.08	1.23		
0:02:39	18.64	1.12	9.14	0.23	0.24	3.86		
0:03:10	17.85	1.6	11.63	0.25	0.4	6.56		
0:03:40	17.2	1.75	10.65	0.27	0.45	7.36		
0:04:12	17.06	1.75	11.28	0.26	0.5	8.12		
0:04:42	16.92	1.8	16.13	0.47	0.74	12.05		
0:05:13	17.05	1.92	19.34	0.51	0.85	13.81		
0:05:44	16.96	1.99	23.63	0.62	1.06	17.23		
0:06:15	16.42	2.1	25.85	0.66	1.33	21.59	123	
0:06:45	16.04	2.15	30.43	0.71	1.71	27.71		
0:07:16	15.77	2.19	34.32	0.95	2.05	33.15	130	
0:07:46	15.9	2.29	36.37	1.07	2.1	34		
0:08:17	16.1	2.34	39.66	1.1	2.18	35.39	136	15
0:08:48	16.33	2.36	40.22	1.03	2.09	33.92		
0:09:20	16.41	2.39	40.83	1.1	2.08	33.7	135	
0:09:50	16.48	2.37	40.36	1.06	2.02	32.77		
0:10:21	16.48	2.38	41.98	1.13	2.1	34.05	136	15
0:10:51	16.54	2.35	38.79	0.83	1.92	31.07		
0:11:22	16.54	2.33	40.99	1	2.03	32.86	134	
0:11:53	16.52	2.31	40.42	1.09	2.01	32.58		
0:12:23	16.57	2.26	38.2	0.96	1.88	30.49	141	12

Table 50. Subject 001 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.21	2.1	28.17	1.22	1.17	12.72	67	
0:01:06	17.78	2.09	27.71	0.87	0.95	10.35		
0:01:37	17.49	2.15	23.74	0.72	0.9	9.77	54	
0:02:08	17.33	2.2	23.04	0.96	0.92	9.96		6
0:02:38	16.93	2.34	21.61	0.57	0.96	10.45	67	
0:03:09	16.57	2.4	21.62	0.68	1.06	11.5		
0:03:40	16.38	2.41	19.26	0.74	0.99	10.74	65	
0:04:11	15.97	2.54	21.36	0.69	1.2	13.03		6
0:04:42	16.08	2.55	20.04	0.61	1.09	11.9	69	
0:05:12	16.18	2.54	20.68	0.98	1.11	12.02		
0:05:43	16.38	2.57	21.43	0.79	1.09	11.84	65	
0:06:15	16.39	2.58	21.43	0.89	1.09	11.81		6
0:06:45	16.46	2.52	25.72	0.86	1.28	13.96		
0:07:16	16.53	2.47	25.57	0.8	1.26	13.68	79	
0:07:47	16.5	2.57	27.34	1.01	1.35	14.64		
0:08:17	16.42	2.59	25.9	0.81	1.3	14.15	75	
0:08:47	16.2	2.61	27.32	1.01	1.45	15.76		7
0:09:18	16.44	2.57	26.29	1.1	1.32	14.32	72	
0:09:49	16.25	2.58	26.26	1.05	1.38	14.96		
0:10:20	16.25	2.53	26.73	0.95	1.41	15.29	71	
0:10:51	16.26	2.51	27.77	1.26	1.46	15.84		7
0:11:22	16.24	2.52	27.2	1.09	1.43	15.57	74	
0:11:52	16.25	2.49	27.78	1.03	1.46	15.91		
0:12:23	16.34	2.49	27.91	1.12	1.44	15.64	78	
0:12:55	16.35	2.52	26.31	1.14	1.35	14.7		7
0:13:25	16.24	2.55	30.55	1.17	1.61	17.47		
0:13:56	16.52	2.48	31.45	1.21	1.55	16.84	85	
0:14:27	16.44	2.53	31.57	1.17	1.58	17.2		
0:14:57	16.21	2.57	35.92	1.28	1.9	20.69	87	
0:15:28	16.25	2.57	31.6	1.09	1.66	18.03		7
0:15:58	16.07	2.63	35.08	1.1	1.91	20.81	86	
0:16:29	16.15	2.62	33.83	1.21	1.82	19.73		
0:17:00	16.19	2.59	33.59	1.29	1.79	19.43		
0:17:30	16.15	2.59	35.38	1.22	1.9	20.63		7
0:18:01	16.42	2.55	33.53	0.93	1.69	18.36	86	
0:18:32	16.21	2.61	33.34	1.23	1.76	19.17		
0:19:03	16.08	2.64	35.42	1.14	1.93	20.94	87	
0:19:34	16.18	2.62	34.68	1.24	1.85	20.07		
0:20:05	16.31	2.56	31.92	1.23	1.65	17.94		
0:20:36	16.04	2.66	41.27	1.25	2.26	24.61		
0:21:07	16.53	2.52	44.49	1.39	2.18	23.75		
0:21:37	16.45	2.59	48.21	1.46	2.4	26.1	112	
0:22:08	16.18	2.64	47.06	1.38	2.5	27.22		
0:22:39	15.97	2.7	51.44	1.43	2.86	31.14	110	
0:23:09	16.13	2.7	50.14	1.39	2.69	29.24		11
0:23:40	16.01	2.75	49.17	1.4	2.7	29.38	116	

Table 50. Subject 001 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:11	16.12	2.74	53.91	1.5	2.89	31.45		
0:24:42	16.2	2.71	52.32	1.41	2.76	29.97	124	
0:25:12	16.07	2.75	51.32	1.35	2.79	30.27		11
0:25:43	16.06	2.75	52.39	1.22	2.85	30.97	119	
0:26:14	16.03	2.76	52.62	1.5	2.88	31.32		
0:26:45	16.08	2.76	52.22	1.41	2.82	30.69	122	
0:27:16	16.15	2.73	53.83	1.42	2.87	31.22		11
0:27:47	16.27	2.69	54.34	1.36	2.82	30.69		
0:28:18	16.25	2.7	61.98	1.55	3.23	35.09		
0:28:48	16.37	2.73	65.24	1.52	3.29	35.8	153	
0:29:19	16.35	2.76	72.57	1.58	3.68	39.99		
0:29:50	16.71	2.74	77.74	1.65	3.59	39.04	156	13
0:30:21	16.77	2.72	78.71	1.67	3.58	38.93		
0:30:51	16.71	2.72	78.42	1.51	3.63	39.46	159	
0:31:22	16.78	2.65	78.85	1.58	3.6	39.09		
0:31:53	16.78	2.65	79.09	1.58	3.61	39.2	160	15
0:32:24	16.78	2.66	82.26	1.52	3.74	40.66		
0:32:55	16.88	2.63	81.49	1.51	3.61	39.25	163	
0:33:25	16.8	2.66	84.03	1.45	3.8	41.3		
0:33:56	16.75	2.65	81.68	1.43	3.75	40.76	162	15
0:34:27	16.68	2.72	46.85	0.76	2.18	23.74		
0:34:58	16.63	2.74	8.3	0.18	0.39	4.26		

Table 51. Subject 002 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.71	1.88	12.54	0.3	0.45	7.74	87	
0:01:06	17.48	1.93	11.09	0.38	0.43	7.38	92	
0:01:37	17.54	1.91	11.45	0.33	0.43	7.49	96	
0:02:08	17.69	1.87	11.65	0.33	0.42	7.25	93	9
0:02:39	17.86	1.8	12.6	0.27	0.43	7.42	96	
0:03:10	17.85	1.78	11.78	0.29	0.4	6.97	90	
0:03:40	17.73	1.84	10.6	0.22	0.38	6.52	93	
0:04:11	17.68	1.85	12.38	0.38	0.45	7.75		9
0:04:42	17.63	1.87	10.59	0.27	0.39	6.74	93	
0:05:13	17.68	1.87	11.26	0.27	0.41	7.03	95	
0:05:44	17.52	1.88	11.27	0.25	0.43	7.42		9
0:06:15	17.54	1.87	9.47	0.33	0.36	6.2		
0:06:45	17.61	1.86	12.61	0.36	0.47	8.06		
0:07:16	17.28	2.01	11.74	0.3	0.48	8.28		
0:07:47	17.32	2.04	14.64	0.52	0.59	10.18		
0:08:19	16.78	2.24	14.48	0.63	0.68	11.66		
0:08:49	16.62	2.36	16.09	0.57	0.78	13.4	96	9
0:09:19	16.47	2.45	15.55	0.39	0.78	13.42		
0:09:50	16.53	2.43	16.69	0.48	0.82	14.2		
0:10:21	16.58	2.42	14.67	0.41	0.71	12.3		
0:10:51	16.58	2.41	14.81	0.41	0.72	12.44	97	9
0:11:22	16.56	2.38	16.34	0.56	0.8	13.83	93	
0:11:53	16.55	2.4	16.7	0.51	0.82	14.16	94	
0:12:24	16.74	2.43	13.52	0.52	0.63	10.89		
0:12:55	16.77	2.45	14.28	0.53	0.66	11.37	91	9
0:13:26	16.47	2.5	16.13	0.5	0.8	13.88		
0:13:57	16.67	2.41	19.16	0.6	0.91	15.72	104	
0:14:28	16.72	2.45	18.21	0.42	0.85	14.71	104	
0:14:58	16.31	2.54	19.44	0.65	1.01	17.36		
0:15:29	16.25	2.59	19.13	0.62	1	17.29	102	
0:15:59	16.31	2.59	19.94	0.83	1.03	17.74	111	
0:16:31	16.47	2.51	18.85	0.51	0.94	16.2	109	
0:17:01	16.44	2.48	16.96	0.63	0.85	14.71	102	9
0:17:31	16.28	2.6	20.35	0.66	1.06	18.24	107	
0:18:02	16.59	2.47	20.15	0.58	0.98	16.84	106	
0:18:33	16.47	2.5	19.9	0.71	0.99	17.11	108	
0:19:04	16.46	2.52	17.75	0.35	0.89	15.27		9
0:19:35	16.28	2.61	22.2	0.52	1.16	19.92		
0:20:06	16.57	2.5	26.14	0.5	1.27	21.9	131	
0:20:36	16.58	2.53	27.63	0.92	1.34	23.07	138	
0:21:07	16.76	2.54	32.63	1.05	1.5	25.93	143	
0:21:38	16.85	2.52	30.8	0.79	1.39	23.88	143	
0:22:09	16.84	2.51	32.72	0.96	1.48	25.49	143	13
0:22:40	16.95	2.47	32.03	1.1	1.41	24.24	137	
0:23:11	16.84	2.49	32.76	0.96	1.48	25.54	134	
0:23:41	16.95	2.43	29.16	0.83	1.28	22.08	135	

Table 51. Subject 002 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:12	16.6	2.52	31.53	0.83	1.52	26.2	139	
0:24:43	16.83	2.48	31.57	0.99	1.43	24.69	142	
0:25:14	16.86	2.46	29.65	0.93	1.34	23.03	144	
0:25:45	16.69	2.54	31.69	1.09	1.49	25.67	145	
0:26:15	16.89	2.5	27.88	0.9	1.24	21.41	150	13
0:26:46	16.63	2.6	31.97	0.89	1.52	26.26		
0:27:17	16.95	2.49	32.08	0.92	1.41	24.25	157	
0:27:48	16.88	2.55	32.99	0.89	1.47	25.36	155	
0:28:18	16.75	2.57	33.09	1	1.53	26.31	151	15
0:28:49	16.84	2.52	33.78	0.94	1.53	26.33	149	
0:29:20	16.85	2.51	33.59	0.99	1.51	26.1	152	
0:29:51	16.84	2.5	33.4	1.01	1.51	26.03	152	
0:30:22	16.72	2.52	32.53	0.96	1.52	26.17	150	
0:30:52	16.73	2.5	35.93	1.03	1.67	28.83	153	15
0:31:24	16.86	2.47	34.94	0.92	1.57	27.15	153	
0:31:54	16.8	2.48	35.89	1	1.64	28.31	153	
0:32:25	16.84	2.47	34.88	1.03	1.58	27.25	152	
0:32:56	16.9	2.45	35.39	1.01	1.58	27.22		15

Table 52. Subject 023 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	19.55	1.01	12.13	0.33	0.18	3.84	93	
0:01:07	18.39	1.52	9.33	0.17	0.26	5.58	85	
0:01:37	18.03	1.86	7.64	0.14	0.24	5.18	93	
0:02:08	17.99	1.9	10.11	0.25	0.33	6.93	90	7
0:02:39	17.93	1.9	17.26	0.69	0.57	12.13	92	
0:03:10	17.85	1.98	17.71	0.32	0.6	12.72	87	
0:03:41	17.58	2.08	19.92	0.55	0.73	15.63	88	
0:04:12	17.14	2.16	22.8	0.57	0.96	20.52	85	
0:04:42	17.03	2.24	25.61	0.91	1.12	23.73	88	8
0:05:13	17.13	2.27	25.48	0.67	1.07	22.84	89	
0:05:43	17.17	2.3	26.79	0.89	1.11	23.67	92	
0:06:14	17.26	2.32	28.76	1.11	1.16	24.67	87	8
0:06:45	17.35	2.36	28.15	1.08	1.1	23.39		
0:07:16	17.4	2.36	28.17	1.13	1.08	23.06		
0:07:47	17.45	2.34	29.16	1.08	1.11	23.53	93	
0:08:18	17.31	2.38	30.67	1.02	1.21	25.82	88	
0:08:48	17.5	2.29	25.53	0.82	0.96	20.32	90	
0:09:19	17.18	2.38	28.75	0.82	1.18	25.2	90	8
0:09:50	17.12	2.41	28.65	1.3	1.2	25.51	85	
0:10:21	17.33	2.35	30.22	1.31	1.19	25.29	92	
0:10:51	17.49	2.26	25.93	0.89	0.98	20.76	90	
0:11:23	17.59	2.24	24.03	0.92	0.87	18.6	92	8
0:11:54	18.13	2.06	13.26	0.36	0.4	8.46	88	
0:12:24	17.96	2.16	11.24	0.4	0.36	7.64	94	
0:12:54	17.92	2.16	8.98	0.21	0.29	6.2	93	
0:13:26	17.87	2.15	8.55	0.1	0.28	6.02	92	8
0:13:56	17.84	2.15	12.4	0.17	0.42	8.85		
0:14:27	18.02	1.99	17.65	0.39	0.56	11.9	103	
0:14:57	18.13	2.06	18.98	0.5	0.57	12.11	112	
0:15:29	17.82	2.07	20.2	0.47	0.68	14.57	111	
0:16:00	17.32	2.17	24.62	0.85	0.98	20.92	112	9
0:16:30	17.22	2.19	29.24	0.89	1.2	25.62	111	
0:17:01	17.22	2.26	28.49	1.29	1.17	24.86	111	
0:17:31	17.16	2.4	36.25	1.34	1.5	31.98	112	
0:18:02	17.48	2.35	35.83	1.43	1.34	28.59	112	10
0:18:33	17.48	2.39	37.99	1.31	1.42	30.26	108	
0:19:04	17.53	2.38	36.3	1.25	1.34	28.43	114	
0:19:35	17.52	2.35	37.62	1.3	1.39	29.63	116	
0:20:06	17.51	2.37	40.05	1.38	1.48	31.58	117	10
0:20:36	17.57	2.33	39.2	1.51	1.43	30.37		
0:21:08	17.61	2.32	40.19	1.26	1.44	30.73		
0:21:38	17.58	2.3	40.28	1.44	1.46	31.11		
0:22:09	17.54	2.34	38.79	1.21	1.42	30.28		

Table 53. Subject 145 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.85	2	24.68	0.62	0.83	9.04		
0:01:06	17.07	2.22	23.85	0.75	1.03	11.16	76	
0:01:37	16.95	2.31	24.95	0.69	1.11	12.02		
0:02:08	17.28	2.21	22.56	0.63	0.91	9.91	80	8
0:02:39	16.82	2.31	24.68	0.95	1.13	12.31		
0:03:10	16.98	2.3	25.96	0.79	1.14	12.42	81	
0:03:41	17.21	2.26	26.45	0.8	1.09	11.83		
0:04:12	17.37	2.25	25.4	0.79	1	10.82	73	8
0:04:42	17.39	2.25	26.43	0.73	1.03	11.16		
0:05:13	17.4	2.25	22.67	0.84	0.88	9.54	75	
0:05:43	17.36	2.24	23.17	0.83	0.91	9.91		
0:06:14	17.21	2.24	23.34	0.73	0.96	10.44	79	8
0:06:44	17.16	2.25	27.32	1.19	1.14	12.4		
0:07:15	17.35	2.25	24.22	0.76	0.96	10.38		
0:07:47	17.04	2.33	25.49	0.94	1.1	11.95	79	
0:08:18	16.97	2.38	25.42	0.62	1.11	12.11		
0:08:48	17	2.37	27.64	0.77	1.2	13.08	89	9
0:09:20	16.92	2.38	29.68	0.99	1.32	14.34		
0:09:50	17.18	2.3	27.08	0.97	1.12	12.19	85	
0:10:20	17.02	2.35	31.05	0.97	1.34	14.61		
0:10:51	17.31	2.3	28.58	0.89	1.14	12.36	86	
0:11:22	17.14	2.35	27.13	0.78	1.14	12.34		9
0:11:52	17	2.4	27.45	0.91	1.19	12.95	86	
0:12:23	17.07	2.39	27.4	1.01	1.16	12.66		
0:12:55	17.27	2.35	30.21	1.01	1.21	13.18	83	9
0:13:26	17.33	2.31	26.28	1.09	1.04	11.3		
0:13:56	17.23	2.33	30	1.03	1.22	13.28		
0:14:27	16.99	2.38	36.47	1.14	1.59	17.28	99	
0:14:58	17.07	2.33	38.57	1.21	1.65	17.9		
0:15:28	16.94	2.38	34.88	1.03	1.54	16.76	98	
0:15:59	16.74	2.48	37.61	1.07	1.75	18.99		10
0:16:29	16.97	2.42	37.86	1.26	1.66	18	95	
0:17:00	17	2.39	39.28	1.27	1.7	18.53		
0:17:31	17.06	2.41	38.72	1.21	1.65	17.94	97	
0:18:02	16.98	2.42	38.82	1.29	1.7	18.43		10
0:18:33	17.09	2.41	36.56	1.22	1.54	16.77	102	
0:19:05	16.85	2.45	39.28	1.4	1.77	19.29		
0:19:35	17.05	2.4	32.43	0.98	1.39	15.09	107	
0:20:06	16.37	2.56	41.39	1.22	2.11	22.91	106	10
0:20:36	16.94	2.51	41.43	1.34	1.82	19.75		
0:21:06	17.07	2.49	47.52	1.44	2.01	21.87	121	
0:21:37	17.2	2.45	52.73	1.43	2.15	23.38		
0:22:08	17.16	2.45	54.89	1.57	2.26	24.59	128	
0:22:39	17.16	2.45	58.76	1.59	2.43	26.37		11
0:23:10	17.32	2.38	63.03	1.66	2.49	27.05	133	
0:23:41	17.27	2.37	60.14	1.63	2.41	26.19		

Table 53. Subject 145 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:12	17.21	2.4	62.92	1.66	2.56	27.87	136	
0:24:42	17.36	2.37	66.7	1.8	2.6	28.28		11
0:25:14	17.45	2.34	65.12	1.63	2.47	26.83	141	
0:25:44	17.36	2.37	67.36	1.77	2.62	28.52		
0:26:14	17.51	2.31	65.93	1.65	2.46	26.72	143	
0:26:45	17.42	2.3	66.12	1.74	2.54	27.58	142	12
0:27:16	17.29	2.33	61.87	1.51	2.47	26.84		
0:27:47	17.07	2.41	69.49	1.78	2.96	32.14		
0:28:18	17.21	2.38	72.61	1.61	2.97	32.24	156	
0:28:48	17.13	2.46	78.15	1.91	3.25	35.33		
0:29:20	17.43	2.41	88.92	1.98	3.37	36.65	162	
0:29:51	17.71	2.33	94.66	2.2	3.27	35.57		13
0:30:21	17.79	2.29	89.71	2.04	3.03	32.89	162	
0:30:52	17.68	2.33	96.64	2.15	3.39	36.82		
0:31:22	17.73	2.31	93.99	2.14	3.23	35.14	161	
0:31:53	17.78	2.26	93.84	2.18	3.19	34.67		14
0:32:24	17.62	2.32	90.18	2.05	3.22	35.05	161	
0:32:55	17.67	2.26	91.77	1.91	3.24	35.25		
0:33:25	17.56	2.28	92.21	2.1	3.38	36.72	162	
0:33:56	17.69	2.25	96.29	2.09	3.38	36.75	164	14
0:34:28	17.72	2.23	90.7	1.97	3.15	34.24		
0:34:59	17.48	2.33	21.58	0.39	0.81	8.82		

Table 54. Subject 173 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	18.45	1.98	21.91	0.71	0.57	7.64		
0:01:06	17.58	2.24	21.11	0.57	0.77	10.26	98	
0:01:37	17.13	2.35	23.43	0.76	0.98	13.1		
0:02:08	16.87	2.43	21.08	0.54	0.95	12.64	93	7
0:02:39	16.79	2.46	21.74	0.68	1	13.3		
0:03:11	16.82	2.47	23.29	0.71	1.06	14.12	95	
0:03:41	16.79	2.53	23.95	0.92	1.1	14.6		
0:04:11	17.11	2.43	23.38	0.63	0.98	13.1	91	7
0:04:41	17.18	2.41	21.91	0.71	0.9	12.01		
0:05:13	17.09	2.46	20.89	0.7	0.88	11.74	94	
0:05:43	16.91	2.54	22.78	0.91	1.01	13.41		
0:06:15	17	2.53	20.74	0.69	0.89	11.91	94	7
0:06:46	16.95	2.58	24.56	0.85	1.07	14.27		
0:07:17	17.11	2.52	27.56	0.89	1.15	15.34	116	
0:07:46	17.06	2.59	28.83	1.11	1.22	16.21		
0:08:17	16.97	2.7	31.97	1.52	1.38	18.34	113	
0:08:48	17.16	2.69	29.85	1.36	1.21	16.17		7
0:09:19	17.25	2.69	29.27	1.05	1.16	15.43	107	
0:09:50	17.04	2.71	30.56	1.09	1.29	17.14		
0:10:21	16.9	2.76	29.26	1.27	1.28	17.06	108	
0:10:52	17	2.77	29.75	1.19	1.26	16.84		9
0:11:22	17.02	2.71	30.71	1.14	1.3	17.32	115	
0:11:53	17.1	2.67	30	1.15	1.24	16.58		
0:12:24	16.99	2.71	30.55	1.39	1.31	17.42	115	
0:12:55	17.06	2.73	31.66	1.22	1.32	17.65	110	9
0:13:26	17.23	2.64	30.55	1.18	1.22	16.27		
0:13:57	17.06	2.7	30.6	1.09	1.28	17.08	119	
0:14:28	16.92	2.72	33.53	1.12	1.46	19.47		
0:14:58	16.83	2.73	36.03	1.33	1.61	21.5	119	
0:15:29	17	2.72	35.32	1.31	1.5	20.03		10
0:16:00	17.01	2.73	36.4	1.3	1.54	20.58	116	
0:16:30	16.93	2.78	37.62	1.39	1.63	21.73		
0:17:02	17.01	2.73	36.86	1.32	1.56	20.87	123	
0:17:33	16.95	2.75	37.68	1.4	1.63	21.69		11
0:18:03	17.01	2.78	34.94	1.29	1.48	19.74	119	
0:18:33	16.92	2.81	32.66	1.02	1.41	18.86		
0:19:04	16.75	2.85	37.78	1.26	1.71	22.86	126	
0:19:35	16.85	2.8	36.52	1.3	1.61	21.53	122	11
0:00:36	16.61	2.85	42.05	1.62	1.98	26.46		
0:01:06	16.63	2.9	44.4	1.53	2.08	27.68	111	
0:01:37	16.61	2.99	48.62	1.87	2.27	30.33		
0:02:09	16.96	2.9	52.06	1.86	2.22	29.61	142	11
0:02:40	17.01	2.9	52.75	1.7	2.21	29.51		
0:03:11	17.07	2.87	48.9	1.63	2.02	26.94	142	
0:03:41	16.98	2.89	54.29	1.75	2.3	30.7		

Table 54. Subject 173 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:04:11	17.01	2.88	53.84	1.42	2.27	30.21	143	13
0:04:42	17.12	2.82	52.56	1.46	2.14	28.57		
0:05:13	17.09	2.83	53.36	1.78	2.2	29.3	147	
0:05:44	17.02	2.85	49.84	1.61	2.09	27.86		
0:06:15	16.88	2.9	49.77	1.56	2.17	28.92	146	14
0:06:46	16.79	2.9	50.2	1.67	2.24	29.93		
0:07:16	16.9	2.88	38.97	1.26	1.69	22.54		
0:07:46	16.88	2.91	39.79	1.53	1.74	23.14		
0:08:18	17.48	2.73	30.39	0.57	1.11	14.78		
0:08:48	17.84	2.6	23.95	0.8	0.77	10.31		
0:09:20	18.14	2.45	20	0.61	0.58	7.69		
0:09:51	18.14	2.42	14.41	0.53	0.42	5.57		
0:10:21	17.92	2.48	16.18	0.45	0.51	6.8		
0:10:52	18.04	2.37	12.29	0.31	0.37	4.97		
0:11:22	17.84	2.4	10.74	0.22	0.35	4.7		
0:11:53	17.58	2.49	14.12	0.29	0.51	6.74		
0:12:25	17.59	2.49	20.43	0.55	0.73	9.74		
0:12:56	17.92	2.41	28.52	1.19	0.91	12.08		
0:13:27	17.27	2.69	32.35	1.29	1.27	16.93		
0:13:57	16.74	2.8	42.01	1.56	1.92	25.6		
0:14:27	16.79	2.76	48.08	1.72	2.17	28.95		
0:14:58	16.71	2.85	51.97	2.08	2.38	31.8	153	
0:15:29	16.76	2.93	56.42	2.26	2.54	33.9		
0:16:00	16.86	2.96	54.28	1.81	2.37	31.62	155	13
0:16:31	16.55	3.11	55.77	2.07	2.64	35.14		
0:17:02	16.79	3.07	59.42	2.2	2.63	35.13	157	
0:17:32	16.95	3.02	61.95	2.14	2.63	35.03		
0:18:02	17	2.98	60.77	2.17	2.54	33.9	161	14
0:18:34	16.88	3.02	62.51	2.32	2.71	36.07		
0:19:05	16.9	2.99	59.05	2.11	2.54	33.93	163	
0:19:36	16.75	3.06	62.48	2.31	2.81	37.42		
0:20:07	16.92	2.99	64.07	2.37	2.75	36.63	164	
0:20:38	16.98	2.99	62.22	1.94	2.62	34.96	162	13
0:21:07	16.93	2.99	62.55	2.16	2.68	35.67		
0:21:38	17.09	2.91	24.08	0.32	0.99	13.15		

Table 55. Subject 214 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:35	17.37	2.2	24.68	0.59	0.97	12.59		
0:01:06	17.18	2.45	26.01	0.7	1.07	13.85	90	
0:01:37	16.49	2.62	27.68	1.11	1.37	17.71		
0:02:08	16.27	2.64	27.46	1.1	1.43	18.53	89	6
0:02:39	16.19	2.68	28.39	0.79	1.5	19.52		
0:03:09	16.3	2.65	26.71	0.92	1.38	17.9	84	
0:03:40	16.3	2.67	28.32	1.13	1.46	18.97		
0:04:11	16.43	2.63	27.12	1	1.36	17.6	87	
0:04:41	16.27	2.73	26.92	1.17	1.39	18.07		
0:05:12	16.34	2.72	26.32	1.01	1.34	17.38	89	
0:05:43	16.3	2.75	26.92	1.08	1.38	17.95		
0:06:14	16.52	2.64	26.4	1.06	1.29	16.75	87	6
0:06:44	16.47	2.66	28.74	1.2	1.42	18.42		
0:07:15	16.45	2.61	28.36	1.09	1.41	18.32	104	
0:07:47	16	2.82	29.09	1.26	1.6	20.75		
0:08:17	15.78	2.84	28.85	1.07	1.66	21.58	98	
0:08:48	15.61	2.92	29.28	0.98	1.75	22.66		7
0:09:18	15.61	2.91	34.54	1.33	2.06	26.7	100	
0:09:49	16.08	2.8	29.35	1.28	1.59	20.57		
0:10:20	15.87	2.9	31.35	1.04	1.77	22.94	101	
0:10:50	15.78	2.9	32.75	1.36	1.88	24.44		7
0:11:21	15.94	2.85	31.75	1.22	1.77	22.91	100	
0:11:52	15.81	2.9	29.3	1.22	1.68	21.74		
0:12:24	15.71	2.92	30.19	1.37	1.76	22.88	100	
0:12:54	15.69	2.91	29.78	1.49	1.75	22.64	99	7
0:13:24	15.71	2.92	32.56	1.36	1.9	24.67		
0:13:55	15.86	2.9	31.67	1.22	1.79	23.21	106	
0:14:26	15.9	2.92	35.32	1.47	1.98	25.64		
0:14:57	15.96	2.89	33.09	1.07	1.83	23.71	113	
0:15:27	15.74	2.94	32.99	1.18	1.91	24.78		8
0:15:58	15.79	2.94	35.86	1.12	2.06	26.68	108	
0:16:29	15.84	2.9	33.19	1.38	1.89	24.46		
0:17:00	15.74	2.9	35.77	1.12	2.07	26.91	111	
0:17:31	15.79	2.89	33.36	1.24	1.91	24.83		8
0:18:02	15.83	2.9	35.77	1.38	2.04	26.4	111	
0:18:33	15.77	2.93	34.37	1.37	1.98	25.68		
0:19:04	15.87	2.92	36.01	1.44	2.03	26.3	113	
0:19:34	15.94	2.93	35.14	1.13	1.95	25.26	110	8
0:20:05	15.87	2.9	36.09	1.34	2.04	26.4		
0:20:36	16.25	2.81	27.55	1.31	1.43	18.52		
0:21:06	16.47	2.69	22.12	1.05	1.09	14.17		
0:21:37	16.99	2.46	18.6	0.64	0.81	10.46		
0:22:08	17.38	2.31	16.36	0.63	0.64	8.24		
0:22:39	17.57	2.24	14.73	0.57	0.54	7		
0:23:09	17.66	2.16	13.11	0.49	0.47	6.07		
0:23:40	17.45	2.15	14.26	0.45	0.55	7.09		
0:24:10	17.1	2.23	21.22	0.41	0.9	11.72		
0:24:41	17.01	2.49	19.06	0.61	0.82	10.66		

Table 55. Subject 214 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:25:12	17.07	2.53	23.14	0.8	0.98	12.67		
0:25:43	16.8	2.58	25.43	0.88	1.16	15.01		
0:26:14	16.05	2.85	30.89	1.19	1.68	21.73		
0:26:45	15.27	3.04	35.97	1.24	2.29	29.66	127	
0:27:16	15.19	3.1	38.38	1.92	2.48	32.1		
0:27:46	15.32	3.16	43.73	1.75	2.74	35.52	131	
0:28:17	15.34	3.21	41.39	1.97	2.58	33.42		11
0:28:48	15.43	3.24	44.48	1.85	2.72	35.22	130	
0:29:19	15.63	3.17	43.07	2.05	2.53	32.82		
0:29:49	15.49	3.27	41.37	2.43	2.49	32.34	135	
0:30:20	15.38	3.32	44.7	2.03	2.75	35.61		11
0:30:51	15.55	3.23	45.91	2.19	2.74	35.47	142	
0:31:22	15.62	3.18	44.38	1.78	2.61	33.83		
0:31:53	15.81	3.14	44.81	1.72	2.53	32.86	140	
0:32:23	15.68	3.14	46.54	2.12	2.71	35.1	142	12
0:32:54	15.83	3.09	47.55	1.76	2.68	34.8		
0:33:25	16.06	2.93	44.33	2.02	2.39	30.97		
0:33:56	16.18	2.94	38.82	1.85	2.03	26.35		
0:34:27	16.87	2.74	33.85	1.3	1.49	19.38		
0:34:58	17.39	2.53	24.87	0.99	0.95	12.33		
0:35:28	17.4	2.4	20.22	0.7	0.78	10.06		
0:35:59	17.74	2.23	19.02	0.59	0.66	8.5		
0:36:30	17.6	2.22	16.11	0.54	0.58	7.59		
0:37:01	17.62	2.2	13.61	0.31	0.49	6.39		
0:37:32	17.62	2.13	15.37	0.33	0.56	7.23		
0:38:02	17.46	2.16	15.87	0.34	0.61	7.86		
0:38:34	17.33	2.18	15.37	0.37	0.61	7.94		
0:39:04	17.25	2.3	14.86	0.29	0.6	7.82		
0:39:35	17.49	2.28	11.1	0.22	0.42	5.4		
0:40:05	17.21	2.3	12.4	0.35	0.51	6.59		
0:40:36	17.23	2.29	21.81	0.7	0.89	11.53		
0:41:07	17.23	2.4	27.89	0.93	1.13	14.66		
0:41:38	16.81	2.72	31.72	1.17	1.43	18.5		
0:42:08	15.75	2.85	34.29	1.27	1.99	25.85		
0:42:38	15.09	2.9	45.51	1.9	3.01	39.07		
0:43:09	15.36	2.98	50.33	2.4	3.15	40.88	160	
0:43:40	15.54	3.11	55.13	2.21	3.31	42.91		
0:44:11	15.66	3.19	60.27	2.74	3.51	45.59	165	13
0:44:42	15.79	3.2	62.3	2.71	3.53	45.8		
0:45:12	16.08	3.12	66.91	3.04	3.56	46.12	171	
0:45:43	15.96	3.18	66.81	2.9	3.64	47.19		
0:46:14	16.15	3.12	68.69	2.75	3.59	46.52	171	14
0:46:45	16.07	3.16	66.8	2.67	3.55	46.1		
0:47:16	15.87	3.2	66.74	2.67	3.71	48.14	175	
0:47:47	15.88	3.13	66.39	2.66	3.7	47.93		
0:48:17	15.92	3.11	71.56	2.98	3.95	51.29	176	
0:48:48	15.93	3.09	64.48	2.8	3.56	46.15	175	15

Table 56. Subject 221 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.54	2.16	15.13	0.3	0.56	7.51		
0:01:07	16.56	2.34	17.26	0.39	0.85	11.31	94	
0:01:38	15.18	2.76	19.1	0.41	1.25	16.66		
0:02:09	14.95	2.86	19.78	0.47	1.35	17.99	88	10
0:02:39	15.14	2.85	18.67	0.46	1.23	16.39		
0:03:09	15.12	2.8	20.94	0.68	1.38	18.46	87	
0:03:41	15.23	2.82	20.79	0.61	1.35	17.94		
0:04:11	15.51	2.81	20.62	0.46	1.26	16.82	95	10
0:04:42	15.56	2.83	20.7	0.58	1.25	16.69		
0:05:12	15.62	2.85	20.03	0.53	1.2	15.95	100	
0:05:43	15.62	2.85	20.66	0.49	1.23	16.46		
0:06:14	15.59	2.83	19.91	0.47	1.2	15.95		10
0:06:45	15.6	2.84	23.28	0.55	1.4	18.6		
0:07:16	15.54	2.88	24.6	0.98	1.49	19.9	112	
0:07:47	15.18	2.98	27.48	0.83	1.79	23.81		
0:08:18	14.81	3.11	26.37	1.1	1.83	24.36	115	11
0:08:48	14.94	3.16	29.33	1.33	1.98	26.38		
0:09:19	15.07	3.18	30.74	1.54	2.02	26.97	117	
0:09:49	15.32	3.1	33.35	1.45	2.1	27.94		
0:10:21	15.64	3.02	31.74	1.51	1.87	24.96	119	12
0:10:51	15.74	3	32.88	1.49	1.9	25.33		
0:11:21	15.8	2.97	31.26	1.25	1.79	23.8	119	
0:11:52	15.77	2.97	33.31	1.19	1.92	25.56		
0:12:23	15.71	2.98	31.97	1.39	1.86	24.79	120	12
0:12:54	15.8	2.98	32.03	1.19	1.83	24.4		
0:13:25	15.74	2.93	33.65	0.99	1.95	25.98		
0:13:56	15.7	2.95	35.06	1.25	2.05	27.28	133	
0:14:27	15.56	3.03	36.73	1.41	2.2	29.34		
0:14:58	15.52	3.07	37.6	1.07	2.27	30.26	138	12
0:15:28	15.71	3.05	39.2	1.4	2.27	30.31		
0:15:59	15.69	3.08	40.68	1.4	2.37	31.56	139	
0:16:30	15.77	3.01	41.06	1.71	2.35	31.39		
0:17:00	15.82	3.03	39.85	1.33	2.26	30.11	144	12
0:17:31	15.89	3.02	41.57	1.48	2.32	30.96		
0:18:02	15.98	2.99	41.32	1.65	2.26	30.15	144	
0:18:32	15.85	3.07	41.14	1.79	2.31	30.83		
0:19:04	15.92	3	41.82	1.44	2.32	30.93	142	12
0:19:34	16.1	2.92	41.87	1.4	2.24	29.83		
0:00:35	17.24	2.33	24	0.34	0.97	12.99		
0:01:07	16.59	2.52	16.31	0.35	0.79	10.51		
0:01:38	16.55	2.53	14.93	0.5	0.73	9.71		
0:02:08	16.86	2.42	14.69	0.42	0.66	8.85		
0:02:38	16.84	2.43	13.1	0.26	0.59	7.93		
0:03:10	16.9	2.46	9.65	0.17	0.43	5.73		
0:03:40	16.42	2.69	16.97	0.45	0.85	11.31		

Table 56. Subject 221 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:04:10	16.78	2.58	20.89	0.55	0.96	12.75		
0:04:41	17.15	2.5	24.5	0.72	1.01	13.5		
0:05:12	15.72	2.79	27.05	0.73	1.58	21.11		
0:05:43	14.65	2.99	33.96	1.17	2.43	32.42		
0:06:13	14.56	3.11	43.49	1.81	3.15	41.98	173	
0:06:44	15.1	3.18	52.42	2.02	3.42	45.66		
0:07:15	15.61	3.2	58.96	2.27	3.47	46.32	179	
0:07:47	15.89	3.17	59.45	1.92	3.3	43.98		14
0:08:17	16.1	3.13	63.47	2.12	3.36	44.78	181	
0:08:47	16.19	3.08	64.97	2.1	3.37	44.93		
0:09:18	16.23	2.98	65.78	1.93	3.4	45.29	186	15
0:09:49	16.13	3.01	64.8	1.91	3.43	45.67		
0:10:20	16.12	3.02	64.06	2	3.39	45.2	189	
0:10:50	16.13	2.99	65.23	2.1	3.45	45.96		
0:11:21	16.21	2.97	65.46	2.11	3.4	45.36	188	15
0:11:52	16.12	3	62.29	1.95	3.3	43.94		
0:12:23	16.27	2.95	56.38	1.71	2.89	38.54		
0:12:54	16.77	2.88	49.16	1.7	2.21	29.5		
0:13:25	17.21	2.74	42.89	1.43	1.71	22.8		
0:13:56	17.34	2.63	38.03	1.36	1.46	19.51		
0:14:27	17.15	2.6	35.45	1.22	1.45	19.36		
0:14:57	17.03	2.6	32.99	1	1.4	18.69		
0:15:28	17.13	2.46	30.63	0.75	1.27	16.98		
0:16:00	17.26	2.33	23.49	0.65	0.95	12.62		
0:16:30	17.12	2.29	23.66	0.55	1	13.32		
0:17:01	16.83	2.36	25.51	0.98	1.17	15.54		
0:17:32	17.18	2.28	21.19	0.56	0.88	11.73		
0:18:03	16.54	2.4	19.71	0.9	0.97	12.95		
0:18:34	16.69	2.43	17.98	0.58	0.85	11.33		
0:19:04	16.96	2.39	18.1	0.6	0.8	10.61		
0:19:35	17.09	2.38	17.13	0.45	0.73	9.67		
0:20:07	17.22	2.34	15.65	0.36	0.64	8.51		
0:20:38	17.3	2.32	13.46	0.52	0.54	7.16		
0:21:08	16.97	2.39	14.16	0.43	0.62	8.27		
0:21:38	16.79	2.39	11.19	0.25	0.52	6.87		
0:22:09	16.6	2.48	19.06	0.56	0.92	12.28		
0:22:40	17.09	2.31	21.95	0.58	0.93	12.46		
0:23:10	16.66	2.44	26.82	0.71	1.28	17.03		
0:23:41	15.3	2.64	31.7	1.17	2.04	27.16		
0:24:12	14.76	2.78	42.36	1.37	3	39.99	179	
0:24:43	15.06	2.84	56.73	1.89	3.79	50.53		
0:25:13	15.78	2.88	61.89	1.77	3.56	47.53	181	
0:25:44	15.69	3.01	60.58	1.89	3.53	47.13		15
0:26:16	15.95	3.01	63.65	1.99	3.51	46.74	182	
0:26:47	16.06	2.99	61.49	1.76	3.31	44.08		
0:27:17	16.07	2.95	63.59	2.12	3.42	45.58	181	

Table 56. Subject 221 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:27:47	16.01	2.95	64.02	2.07	3.49	46.52	182	16
0:28:18	16.1	2.9	63.78	1.64	3.41	45.48		
0:28:49	16.07	2.88	63.05	1.66	3.4	45.33	190	
0:29:20	16.01	2.9	63.04	1.43	3.44	45.93		
0:29:50	16	2.91	64.98	1.76	3.56	47.46	187	18
0:30:21	16.08	2.87	34.17	0.85	1.84	24.52		
0:00:35	16.14	3.06	55.08	1.67	2.9	38.64		
0:01:06	16.24	3.38	65.86	2.35	3.32	44.26	177	
0:01:38	16.7	3.48	73.61	2.45	3.26	43.51		
0:02:08	16.85	3.49	79.86	2.16	3.39	45.18	183	17
0:02:39	17	3.44	77.63	2.1	3.15	42.06		
0:03:10	17.01	3.44	80.02	2.29	3.25	43.27	187	
0:03:40	17.02	3.39	85.92	2.26	3.49	46.52		
0:04:11	16.98	3.36	84.27	2.28	3.46	46.2	189	19
0:04:42	17.05	3.36	86.38	2.16	3.48	46.42		
0:05:13	17.11	3.49	87.42	2.24	3.42	45.57	193	
0:05:44	17.17	3.44	89.57	2.13	3.45	46.03	194	19
0:06:15	17.09	3.46	69.15	1.36	2.73	36.45		

Table 57. Subject 231 condition B.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	18.45	1.88	14.41	0.66	0.38	6.18		
0:01:06	18.12	1.99	14.84	0.42	0.45	7.3	82	
0:01:37	18.08	2.01	16.44	0.69	0.51	8.22		
0:02:09	18.07	2.03	13.91	0.38	0.43	6.97	86	7
0:02:39	18.01	2.01	14.31	0.33	0.45	7.35		
0:03:09	17.9	2.02	18.02	0.82	0.6	9.65	79	
0:03:40	17.93	1.99	13.59	0.4	0.44	7.2		
0:04:11	18.09	1.93	15.16	0.61	0.47	7.58	86	7
0:04:42	17.92	1.99	14.27	0.59	0.47	7.62		
0:05:13	17.83	1.99	15.98	0.55	0.54	8.8	80	
0:05:43	17.82	1.98	14.7	0.4	0.5	8.13		7
0:06:15	17.86	2.01	15.32	0.53	0.51	8.33		
0:06:45	17.91	1.98	15.04	0.38	0.5	8.04		
0:07:16	18.16	1.9	14.15	0.38	0.43	6.91		
0:07:47	18.1	1.92	17.1	0.45	0.53	8.53	86	
0:08:18	17.57	2.11	19.41	0.55	0.72	11.62		
0:08:48	17.53	2.13	18.99	0.65	0.71	11.53	86	7
0:09:19	17.4	2.19	20.09	0.63	0.78	12.69		
0:09:50	17.37	2.16	20.08	0.59	0.79	12.83	82	
0:10:21	17.58	2.11	20.85	0.74	0.77	12.47		
0:10:52	17.61	2.1	20.48	0.66	0.75	12.11	84	7
0:11:23	17.5	2.17	19.42	0.65	0.73	11.87		
0:11:53	17.57	2.14	19.82	0.55	0.73	11.84	86	
0:12:24	17.58	2.15	20.47	0.55	0.75	12.21		
0:12:55	17.59	2.16	19	0.53	0.7	11.28	87	
0:13:26	17.55	2.17	19.85	0.66	0.74	11.95		7
0:13:56	17.55	2.18	21.59	0.67	0.8	12.97	119	
0:14:27	17.48	2.18	21.07	0.73	0.8	12.95		
0:14:58	17.34	2.24	23.06	0.72	0.91	14.77	119	
0:15:28	17.33	2.22	22.43	0.64	0.89	14.43		9
0:15:59	17.38	2.23	23.8	0.88	0.93	15.09	117	
0:16:30	17.25	2.25	22.83	0.71	0.93	15.03		
0:17:01	17.34	2.22	22.77	0.73	0.9	14.6	117	
0:17:31	17.37	2.24	22.3	0.62	0.87	14.17		9
0:18:02	17.4	2.25	23.39	0.69	0.91	14.73	118	
0:18:33	17.38	2.27	23.09	0.77	0.9	14.59		
0:19:04	17.35	2.22	24.17	0.93	0.95	15.45		
0:19:34	17.46	2.21	23.06	0.72	0.88	14.23		10
0:20:05	17.43	2.2	24.52	0.82	0.94	15.3		
0:20:36	17.63	2.17	21.63	0.66	0.78	12.64		
0:21:07	17.7	2.16	16.23	0.36	0.57	9.25		
0:00:36	18.09	2.06	11.37	0.32	0.35	5.63		
0:01:07	17.97	2.02	11.54	0.24	0.37	6.01		
0:01:38	17.8	2.06	12.23	0.24	0.42	6.79		
0:02:08	17.83	2.04	12.68	0.33	0.43	6.96		
0:02:39	18.02	2.05	12.94	0.35	0.41	6.6		
0:03:10	18.12	2.01	17.11	0.45	0.52	8.41		

Table 57. Subject 231 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:03:41	18.09	2.05	21.87	0.71	0.67	10.83		
0:04:11	17.67	2.18	21.8	0.66	0.78	12.58		
0:04:42	17	2.31	26.84	0.75	1.17	18.98	115	
0:05:13	16.87	2.33	29.92	1	1.35	21.93		
0:05:44	16.78	2.37	29.94	0.79	1.39	22.45	117	
0:06:14	16.77	2.44	33.84	1.13	1.56	25.32		13
0:06:45	17.08	2.42	33.3	1.01	1.41	22.84	116	
0:07:16	17.01	2.48	33.65	1.12	1.45	23.49		
0:07:47	17.12	2.47	35.04	1.13	1.46	23.68	117	
0:08:18	17.18	2.48	33.26	0.74	1.36	22.04		14
0:08:49	17.01	2.56	35.94	1.12	1.54	24.97	121	
0:09:19	17.27	2.48	35.28	1.1	1.4	22.76		
0:09:49	17.29	2.45	36.22	1.01	1.43	23.25	121	
0:10:21	17.21	2.42	35.07	1.13	1.43	23.13		14
0:10:51	17.19	2.44	33.52	0.91	1.37	22.26		
0:11:22	17.29	2.4	30.12	0.89	1.2	19.43		
0:11:53	17.5	2.33	22.12	0.51	0.83	13.37		
0:12:24	17.75	2.31	3.78	0.11	0.13	2.09		
0:12:55	17.7	2.34	3.8	0.18	0.13	2.14		
0:13:26	17.73	2.36	3.75	0.1	0.13	2.08		
0:13:58	17.73	2.35	3.51	0.13	0.12	1.95		
0:14:28	17.76	2.34	3.75	0.09	0.13	2.07		
0:14:59	17.76	2.31	3.71	0.18	0.13	2.05		
0:15:30	17.75	2.28	3.87	0.09	0.13	2.15		
0:16:01	17.79	2.28	3.84	0.13	0.13	2.1		
0:16:31	17.82	2.27	3.7	0.11	0.12	2		
0:17:02	17.87	2.27	3.84	0.1	0.13	2.04		
0:17:34	17.88	2.26	3.71	0.15	0.12	1.97		
0:18:05	17.9	2.24	3.69	0.17	0.12	1.94		
0:18:36	18.1	2.08	4.33	0.12	0.13	2.13		
0:19:07	18.74	1.69	3.94	0.12	0.09	1.49		
0:19:37	19.14	1.45	7.71	0.2	0.15	2.36		
0:20:08	18.74	1.63	12.97	0.36	0.3	4.92		
0:20:39	18.3	1.94	9.95	0.2	0.28	4.55		
0:21:10	18.37	1.94	10.3	0.25	0.28	4.55		
0:21:40	18.08	2.01	10.26	0.23	0.32	5.13		
0:22:11	18.52	1.73	17.51	0.45	0.45	7.37		
0:22:42	18.04	2	21.79	0.68	0.68	11.05		
0:23:13	17.48	2.24	24.83	0.71	0.94	15.19		
0:23:44	16.73	2.34	29.2	0.91	1.37	22.26	118	
0:24:14	16.53	2.39	32.03	0.84	1.58	25.61		
0:24:45	16.46	2.4	34.07	1.06	1.71	27.79	124	
0:25:16	16.53	2.53	37.69	1.11	1.85	29.98		15
0:25:47	16.82	2.53	36.53	1.07	1.66	26.89		
0:26:17	16.79	2.6	39.02	1.15	1.78	28.85		
0:26:47	16.82	2.65	39.74	1.24	1.79	29.04	135	
0:27:19	16.94	2.66	41.16	1.14	1.79	29.03		15

Table 57. Subject 231 condition B (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:27:49	16.89	2.66	40.53	1.19	1.79	28.96	134	
0:28:20	17.09	2.6	40.07	1.11	1.67	27.13	134	
0:28:51	16.96	2.64	39.67	0.97	1.72	27.89	136	
0:29:22	17	2.59	40.54	1.1	1.74	28.19	139	15

Table 58. Subject 001 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:37	17.84	2.18	21.41	0.76	0.72	7.78		
0:01:06	17.56	2.26	21.15	1.17	0.78	8.44	65	
0:01:37	16.55	2.54	22.53	1.02	1.1	11.95		
0:02:09	16.49	2.61	21.33	0.82	1.05	11.44	71	6
0:02:39	16.32	2.63	22.55	0.87	1.16	12.61		
0:03:10	16.42	2.6	21.97	0.92	1.1	11.99	65	
0:03:40	16.57	2.56	23.85	0.95	1.16	12.57		
0:04:11	16.53	2.58	23.02	0.92	1.13	12.24	65	6
0:04:42	16.66	2.54	23.93	0.96	1.13	12.33		
0:05:13	16.69	2.54	23.57	1.07	1.11	12.03	70	
0:05:44	16.64	2.58	25.67	0.89	1.22	13.25		
0:06:15	16.86	2.51	27.34	1.01	1.23	13.35	66	6
0:06:45	17.02	2.46	28.76	1.07	1.24	13.45		
0:07:16	17.04	2.47	33.88	1.13	1.45	15.73		
0:07:47	17.18	2.44	33.46	1.12	1.37	14.94	82	6
0:08:17	16.93	2.51	33.43	1.19	1.47	16.01		
0:08:48	16.68	2.56	32.97	1.18	1.55	16.85		6
0:09:18	16.79	2.57	36.12	1.17	1.65	17.91		
0:09:49	17.13	2.51	36.67	1.18	1.52	16.54	85	
0:10:20	17.12	2.48	33.06	1.18	1.38	14.97		
0:10:51	16.81	2.54	33.95	1.13	1.55	16.8	84	6
0:11:21	16.89	2.49	32.22	1.11	1.44	15.61		
0:11:53	16.76	2.54	36	1.24	1.66	18.04	84	
0:12:24	17.06	2.49	35.35	1.22	1.5	16.33		
0:12:54	16.87	2.53	34.83	1	1.56	16.91	85	6
0:13:25	16.95	2.48	35.43	1.07	1.55	16.89		
0:13:55	17.01	2.48	40.55	1.31	1.75	19		
0:14:26	16.9	2.54	42.48	1.37	1.89	20.49	95	
0:14:57	16.77	2.54	40.66	1.31	1.87	20.34		
0:15:27	16.67	2.57	41.73	1.3	1.97	21.36	94	7
0:15:58	16.73	2.55	41.19	1.29	1.92	20.83		
0:16:29	16.61	2.55	41.29	1.38	1.98	21.55	96	
0:17:00	16.55	2.57	41.85	1.35	2.03	22.12		
0:17:31	16.74	2.55	40.46	1.31	1.88	20.39	92	7
0:18:03	16.56	2.58	38.49	1.17	1.87	20.29		
0:18:33	16.41	2.64	41.03	1.28	2.06	22.43	100	
0:19:03	16.49	2.63	41.46	1.34	2.04	22.21		
0:19:35	16.59	2.64	39.86	1.33	1.91	20.8		9
0:20:05	16.69	2.62	43.12	1.35	2.02	21.91		
0:20:35	16.75	2.56	49.56	1.42	2.29	24.86		
0:21:06	16.89	2.57	52.26	1.54	2.32	25.2		
0:21:37	16.45	2.68	55.74	1.59	2.77	30.07	122	
0:22:08	16.24	2.8	56.12	1.65	2.92	31.75		
0:22:39	16.24	2.81	58.32	1.67	3.03	32.92	124	11
0:23:10	16.3	2.82	60.56	1.68	3.1	33.7		
0:23:41	16.37	2.78	61.76	1.54	3.11	33.83	125	

Table 58. Subject 001 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:11	16.42	2.73	64.15	1.73	3.2	34.78		
0:24:42	16.41	2.76	65.69	1.64	3.28	35.64	130	12
0:25:13	16.62	2.67	66.3	1.54	3.15	34.23		
0:25:43	16.67	2.67	66.9	1.59	3.13	34.07	134	
0:26:14	16.67	2.66	64.71	1.54	3.04	33.04		
0:26:44	16.52	2.72	67.24	1.49	3.27	35.59	135	
0:27:15	16.63	2.67	68.93	1.44	3.27	35.52		
0:27:46	16.72	2.64	69.43	1.48	3.22	34.95		
0:28:17	16.64	2.67	74.44	1.52	3.52	38.23	148	
0:28:48	16.6	2.72	78.82	1.61	3.76	40.85		
0:29:19	16.55	2.79	80.34	1.67	3.86	41.94	150	15
0:29:50	16.59	2.8	81.26	1.63	3.87	42.04		
0:30:20	16.64	2.8	82.51	1.65	3.87	42.1	155	
0:30:51	16.68	2.81	86.92	1.58	4.03	43.81		
0:31:21	16.68	2.81	84.57	1.57	3.92	42.62	158	17
0:31:52	16.49	2.88	87.95	1.47	4.27	46.46		

Table 59. Subject 002 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	16.97	2.22	12.33	0.32	0.55	9.42	90	
0:01:06	17.26	2.15	11.02	0.26	0.45	7.74	101	
0:01:38	17.32	2.15	10.6	0.19	0.42	7.33	102	
0:02:08	17.41	2.12	10.32	0.21	0.4	6.94	95	9
0:02:40	17.12	2.13	10.48	0.24	0.45	7.7	100	
0:03:10	17	2.1	10.8	0.31	0.48	8.24	103	
0:03:40	16.91	2.13	11.46	0.22	0.52	8.96	100	
0:04:12	16.95	2.06	12.38	0.29	0.56	9.59	96	9
0:04:42	17.06	2.02	11.26	0.25	0.49	8.48	93	
0:05:13	17.04	2.04	10.58	0.22	0.46	8	98	
0:05:44	16.98	2.11	10.95	0.23	0.49	8.39	99	9
0:06:14	16.99	2.11	12.34	0.33	0.55	9.44		
0:06:45	17.05	2.07	12.97	0.25	0.57	9.76		
0:07:16	16.96	2.09	16.08	0.39	0.72	12.41	94	
0:07:47	16.84	2.16	16.44	0.46	0.76	13.06	98	
0:08:17	16.86	2.22	13.45	0.25	0.61	10.6	97	
0:08:48	16.65	2.23	16.49	0.31	0.8	13.73	95	11
0:09:19	16.43	2.28	16.22	0.54	0.83	14.25	96	
0:09:50	16.48	2.3	16.77	0.45	0.84	14.53	97	
0:10:21	16.67	2.28	15.49	0.62	0.74	12.81	98	
0:10:51	16.82	2.27	14.83	0.53	0.68	11.77	91	11
0:11:22	16.75	2.3	15.17	0.43	0.71	12.26	96	
0:11:53	16.64	2.3	14.35	0.38	0.69	11.95	94	
0:12:24	16.47	2.32	16.44	0.43	0.83	14.26	92	
0:12:54	16.73	2.25	14.61	0.37	0.69	11.9	98	11
0:13:25	16.77	2.22	15.99	0.37	0.75	12.89		
0:13:56	16.54	2.27	19.96	0.57	0.99	17.04	108	
0:14:26	16.69	2.28	19.56	0.65	0.93	16.06	115	
0:14:58	16.55	2.33	20.85	0.61	1.03	17.7	101	
0:15:28	16.45	2.33	19.64	0.63	0.99	17.12	108	11
0:15:59	16.37	2.4	20.41	0.66	1.05	18.11	109	
0:16:30	16.49	2.34	20	0.56	1	17.24	97	
0:17:01	16.34	2.41	20.97	0.7	1.08	18.7	109	
0:17:32	16.51	2.35	21.13	0.48	1.05	18.16	106	
0:18:03	16.54	2.36	19.87	0.48	0.98	16.92	112	11
0:18:33	16.44	2.38	21.68	0.5	1.1	18.93	112	
0:19:04	16.35	2.41	19.88	0.45	1.03	17.67	112	11
0:19:35	16.41	2.43	20.96	0.52	1.06	18.35	111	
0:20:05	16.55	2.37	24.95	0.76	1.23	21.15	128	
0:20:36	16.64	2.37	26.07	0.74	1.25	21.61		
0:21:06	16.65	2.43	28.42	1.02	1.36	23.39	135	
0:21:37	16.59	2.47	28.1	0.88	1.36	23.45	137	
0:22:08	16.58	2.44	32.37	0.98	1.57	27.12	138	
0:22:39	16.83	2.37	31.46	0.9	1.44	24.74	138	13
0:23:10	16.68	2.41	31.24	0.78	1.48	25.53	140	
0:23:40	16.78	2.39	30.9	0.81	1.43	24.62	142	

Table 59. Subject 002 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:11	16.79	2.43	31.5	0.9	1.45	25.01	141	
0:24:42	16.81	2.43	29.36	0.65	1.34	23.18	144	
0:25:13	16.67	2.48	33.41	0.78	1.58	27.3	141	
0:25:44	16.92	2.41	31.16	0.68	1.38	23.86	140	
0:26:14	16.83	2.44	30.73	0.75	1.4	24.09		13
0:26:45	16.74	2.45	33.01	0.75	1.54	26.53	149	
0:27:17	16.87	2.39	35.95	0.88	1.62	27.94		
0:27:47	17.02	2.36	34.97	0.71	1.51	26.07	149	
0:28:17	16.88	2.42	36.13	0.98	1.62	28	156	
0:28:48	16.96	2.42	38.23	0.87	1.68	28.92	154	
0:29:19	17	2.4	37.69	0.99	1.64	28.25	155	15
0:29:50	17.1	2.43	37.82	1	1.59	27.45	155	
0:30:21	17.05	2.4	37.92	0.9	1.62	27.99	153	
0:30:51	17.09	2.36	36.47	0.87	1.54	26.63	156	
0:31:22	16.94	2.37	37.1	0.93	1.64	28.31	158	
0:31:53	16.97	2.35	33.6	0.65	1.48	25.49	150	
0:32:24	16.62	2.41	37.33	0.93	1.8	31.02	149	
0:32:54	16.7	2.41	36.91	0.84	1.74	30.03	153	15
0:33:25	16.9	2.38	37.73	0.84	1.69	29.13		
0:33:56	16.98	2.35	20.38	0.39	0.89	15.38		

Table 60. Subject 023 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:00:36	16.97	2.22	12.33	0.32	0.55	9.42
0:01:06	17.26	2.15	11.02	0.26	0.45	7.74
0:01:38	17.32	2.15	10.6	0.19	0.42	7.33
0:02:08	17.41	2.12	10.32	0.21	0.4	6.94
0:02:40	17.12	2.13	10.48	0.24	0.45	7.7
0:03:10	17	2.1	10.8	0.31	0.48	8.24
0:03:40	16.91	2.13	11.46	0.22	0.52	8.96
0:04:12	16.95	2.06	12.38	0.29	0.56	9.59
0:04:42	17.06	2.02	11.26	0.25	0.49	8.48
0:05:13	17.04	2.04	10.58	0.22	0.46	8
0:05:44	16.98	2.11	10.95	0.23	0.49	8.39
0:06:14	16.99	2.11	12.34	0.33	0.55	9.44
0:06:45	17.05	2.07	12.97	0.25	0.57	9.76
0:07:16	16.96	2.09	16.08	0.39	0.72	12.41
0:07:47	16.84	2.16	16.44	0.46	0.76	13.06
0:08:17	16.86	2.22	13.45	0.25	0.61	10.6
0:08:48	16.65	2.23	16.49	0.31	0.8	13.73
0:09:19	16.43	2.28	16.22	0.54	0.83	14.25
0:09:50	16.48	2.3	16.77	0.45	0.84	14.53
0:10:21	16.67	2.28	15.49	0.62	0.74	12.81
0:10:51	16.82	2.27	14.83	0.53	0.68	11.77
0:11:22	16.75	2.3	15.17	0.43	0.71	12.26
0:11:53	16.64	2.3	14.35	0.38	0.69	11.95
0:12:24	16.47	2.32	16.44	0.43	0.83	14.26
0:12:54	16.73	2.25	14.61	0.37	0.69	11.9
0:13:25	16.77	2.22	15.99	0.37	0.75	12.89
0:13:56	16.54	2.27	19.96	0.57	0.99	17.04
0:14:26	16.69	2.28	19.56	0.65	0.93	16.06
0:14:58	16.55	2.33	20.85	0.61	1.03	17.7
0:15:28	16.45	2.33	19.64	0.63	0.99	17.12
0:15:59	16.37	2.4	20.41	0.66	1.05	18.11
0:16:30	16.49	2.34	20	0.56	1	17.24
0:17:01	16.34	2.41	20.97	0.7	1.08	18.7
0:17:32	16.51	2.35	21.13	0.48	1.05	18.16
0:18:03	16.54	2.36	19.87	0.48	0.98	16.92
0:18:33	16.44	2.38	21.68	0.5	1.1	18.93
0:19:04	16.35	2.41	19.88	0.45	1.03	17.67
0:19:35	16.41	2.43	20.96	0.52	1.06	18.35
0:20:05	16.55	2.37	24.95	0.76	1.23	21.15
0:20:36	16.64	2.37	26.07	0.74	1.25	21.61
0:21:06	16.65	2.43	28.42	1.02	1.36	23.39
0:21:37	16.59	2.47	28.1	0.88	1.36	23.45
0:22:08	16.58	2.44	32.37	0.98	1.57	27.12
0:22:39	16.83	2.37	31.46	0.9	1.44	24.74
0:23:10	16.68	2.41	31.24	0.78	1.48	25.53
0:23:40	16.78	2.39	30.9	0.81	1.43	24.62

Table 60. Subject 023 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)
0:24:11	16.79	2.43	31.5	0.9	1.45	25.01
0:24:42	16.81	2.43	29.36	0.65	1.34	23.18
0:25:13	16.67	2.48	33.41	0.78	1.58	27.3
0:25:44	16.92	2.41	31.16	0.68	1.38	23.86
0:26:14	16.83	2.44	30.73	0.75	1.4	24.09
0:26:45	16.74	2.45	33.01	0.75	1.54	26.53
0:27:17	16.87	2.39	35.95	0.88	1.62	27.94
0:27:47	17.02	2.36	34.97	0.71	1.51	26.07
0:28:17	16.88	2.42	36.13	0.98	1.62	28
0:28:48	16.96	2.42	38.23	0.87	1.68	28.92
0:29:19	17	2.4	37.69	0.99	1.64	28.25
0:29:50	17.1	2.43	37.82	1	1.59	27.45
0:30:21	17.05	2.4	37.92	0.9	1.62	27.99
0:30:51	17.09	2.36	36.47	0.87	1.54	26.63
0:31:22	16.94	2.37	37.1	0.93	1.64	28.31
0:31:53	16.97	2.35	33.6	0.65	1.48	25.49
0:32:24	16.62	2.41	37.33	0.93	1.8	31.02
0:32:54	16.7	2.41	36.91	0.84	1.74	30.03
0:33:25	16.9	2.38	37.73	0.84	1.69	29.13
0:33:56	16.98	2.35	20.38	0.39	0.89	15.38

Table 61. Subject 145 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.62	2.02	24.44	0.72	0.89	9.72		
0:01:07	17.19	2.23	24.17	0.59	1	10.91	80	
0:01:37	17.21	2.24	24.03	0.57	0.99	10.77		
0:02:08	17.06	2.27	26.89	0.77	1.16	12.56	74	7
0:02:39	17.27	2.22	24.36	0.41	0.99	10.73		
0:03:09	17.1	2.18	27.32	0.72	1.17	12.7	85	
0:03:40	17.21	2.16	31.32	0.82	1.3	14.11		
0:04:11	17.68	2.05	29.14	0.79	1.04	11.34	82	7
0:04:42	17.67	2.13	23.38	0.53	0.83	9.04		
0:05:13	17.31	2.16	26.36	0.69	1.06	11.49	82	
0:05:44	17.25	2.19	23.96	0.75	0.98	10.63	85	7
0:06:14	17.14	2.26	24.98	0.93	1.05	11.41		
0:06:45	17.18	2.21	26.93	0.61	1.12	12.2		
0:07:16	17.26	2.23	28.41	0.98	1.15	12.52	87	
0:07:47	17.31	2.23	28.76	0.74	1.15	12.5		
0:08:17	17.34	2.2	30.69	0.83	1.22	13.21	95	
0:08:48	17.31	2.19	29.02	0.97	1.16	12.65		
0:09:19	17.27	2.21	30.44	0.9	1.24	13.43	92	11
0:09:49	17.23	2.2	25.31	0.59	1.04	11.3		
0:10:20	16.8	2.34	31.25	0.92	1.44	15.67	90	
0:10:51	17.12	2.31	28.88	0.66	1.22	13.22		
0:11:21	17.09	2.31	26.49	0.59	1.13	12.24	90	11
0:11:53	16.84	2.33	28.73	0.82	1.31	14.25		
0:12:24	17.08	2.3	28.93	0.78	1.24	13.43	86	
0:12:54	17.13	2.28	28.66	0.61	1.21	13.12	95	11
0:13:25	17.2	2.23	27.7	0.75	1.15	12.45		
0:13:56	16.72	2.36	33.45	0.9	1.57	17.11	105	
0:14:26	17.09	2.31	36.08	1	1.54	16.69		
0:14:56	16.96	2.34	43.46	1.11	1.92	20.82	101	
0:15:28	17.54	2.15	47.18	1.15	1.76	19.13		12
0:15:58	17.6	2.11	32.64	0.73	1.2	13	104	
0:16:29	16.59	2.36	39.58	0.97	1.93	20.94		
0:17:00	17.03	2.25	41.63	0.97	1.81	19.63	107	
0:17:31	17.09	2.29	39.85	0.87	1.7	18.45		12
0:18:01	17.08	2.27	37.74	0.97	1.62	17.56	105	
0:18:33	16.95	2.35	36.65	0.94	1.62	17.6		
0:19:04	16.75	2.37	35.67	0.89	1.66	18.09	105	
0:19:34	16.64	2.42	37.76	1.08	1.81	19.65	105	12
0:20:05	16.83	2.36	37.05	1.2	1.69	18.38		
0:20:36	16.88	2.35	43.04	1.16	1.94	21.1	114	
0:21:06	17.12	2.3	49.61	1.06	2.09	22.72		
0:21:37	17.27	2.21	66.04	1.57	2.67	29.06	124	
0:22:08	17.74	2.1	52.09	1.13	1.81	19.72		13
0:22:39	17.01	2.32	55.37	1.46	2.41	26.2	128	
0:23:09	17.12	2.31	56.7	1.38	2.39	25.95		
0:23:40	17.03	2.35	58.8	1.37	2.54	27.58	124	

Table 61. Subject 145 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:11	17.34	2.27	54.7	1.24	2.16	23.47	133	13
0:24:42	17.07	2.32	54.71	1.33	2.34	25.41	131	
0:25:13	17.05	2.33	64.97	1.71	2.79	30.32	136	
0:25:44	17.75	2.1	63.18	1.5	2.2	23.89	132	
0:26:15	17.3	2.16	61.25	1.39	2.46	26.77	137	13
0:26:45	17.35	2.16	53.83	1.45	2.13	23.19		
0:27:17	16.81	2.34	51.07	1.09	2.35	25.55		
0:00:35	16.76	2.25	51.63	1.08	2.42	26.31		
0:01:06	16.66	2.31	59.51	1.42	2.85	31	146	
0:01:37	16.9	2.35	69.86	1.52	3.13	34.06		
0:02:07	17.23	2.3	74.2	1.65	3.03	32.91	154	14
0:02:38	17.38	2.27	77.41	1.68	3.01	32.77		
0:03:09	17.3	2.3	77.78	1.53	3.1	33.71	152	
0:03:40	17.22	2.33	77.21	1.61	3.15	34.29		
0:04:11	17.38	2.29	86.39	1.6	3.36	36.56	160	14
0:04:42	17.44	2.26	84.31	1.65	3.22	35.01		
0:05:12	17.41	2.24	84.18	1.72	3.25	35.35	161	
0:05:44	17.44	2.27	87.06	1.78	3.33	36.19		
0:06:14	17.44	2.27	83.43	1.7	3.19	34.69	162	16
0:06:45	17.4	2.3	45.3	0.89	1.75	19.01		

Table 62. Subject 173 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:35	18.32	2.05	15.46	0.4	0.43	6.59		
0:01:06	17.76	2.24	17.72	0.52	0.61	9.34	90	
0:01:37	17.14	2.39	17.89	0.72	0.75	11.49		
0:02:08	16.86	2.45	17.87	0.64	0.8	12.38	85	6
0:02:38	16.89	2.44	17.99	0.58	0.8	12.38		
0:03:09	16.78	2.47	17.65	0.68	0.81	12.49	88	
0:03:40	16.84	2.44	18.88	0.65	0.86	13.15		
0:04:11	16.85	2.44	17.05	0.43	0.77	11.87	85	6
0:04:42	16.72	2.47	19.16	0.49	0.9	13.8		
0:05:13	16.94	2.38	18.37	0.63	0.81	12.49	82	
0:05:44	16.78	2.45	19.57	0.67	0.9	13.86		
0:06:14	16.96	2.45	19.56	0.49	0.86	13.19	84	6
0:06:45	17	2.43	21.21	0.66	0.92	14.14		
0:07:16	16.88	2.48	21.92	0.78	0.98	15.11	98	
0:07:46	16.68	2.62	21.93	0.84	1.03	15.83		
0:08:17	16.41	2.7	22.37	1.18	1.12	17.25	99	
0:08:48	16.31	2.73	19.97	0.91	1.02	15.74		7
0:09:19	16.25	2.77	21.1	1.24	1.1	16.87	92	
0:09:49	16.23	2.79	22.5	1.13	1.17	18.05		
0:10:20	16.27	2.82	21.87	1.09	1.13	17.36	98	
0:10:51	16.42	2.79	20.59	0.86	1.02	15.75		8
0:11:22	16.4	2.81	21.3	0.93	1.06	16.35	98	
0:11:53	16.32	2.8	22.13	1.05	1.13	17.35		
0:12:23	16.24	2.86	22.67	1.74	1.17	18.06	99	
0:12:55	16.36	2.84	21.52	0.98	1.08	16.65	100	8
0:13:25	16.47	2.81	23.53	1.02	1.16	17.77		
0:13:56	16.61	2.73	29.25	1.12	1.39	21.38		
0:14:27	16.82	2.65	27.36	1.52	1.23	18.97	113	
0:14:58	16.51	2.76	30.98	1.41	1.51	23.22		
0:15:28	16.5	2.81	29.85	1.42	1.45	22.38	109	9
0:15:59	16.55	2.8	28.33	1.49	1.36	20.95		
0:16:30	16.55	2.82	30	1.36	1.44	22.14	113	
0:17:01	16.59	2.79	30.11	1.31	1.43	22.03		
0:17:31	16.55	2.78	30.12	1.26	1.45	22.29	112	10
0:18:02	16.64	2.79	32.3	1.54	1.51	23.3		
0:18:33	16.64	2.78	29.37	1.63	1.38	21.21	107	
0:19:03	16.54	2.81	30.8	1.47	1.48	22.83		
0:19:34	16.51	2.82	28.34	1.42	1.38	21.17	113	10
0:20:06	16.39	2.86	31.52	1.58	1.57	24.18		
0:20:36	16.49	2.82	24.28	1.16	1.18	18.22		
0:21:07	16.85	2.7	23.07	0.82	1.03	15.82		
0:21:37	17.08	2.63	17.06	0.45	0.71	10.99		
0:22:08	17.46	2.47	16.3	0.47	0.61	9.39		
0:22:39	17.88	2.32	15.57	0.62	0.51	7.78		
0:23:10	17.93	2.3	13.3	0.53	0.42	6.54		
0:23:41	18.19	2.15	8.89	0.27	0.26	3.97		

Table 62. Subject 173 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:11	17.91	2.21	14.5	0.48	0.47	7.22		
0:24:42	17.58	2.29	22.68	0.48	0.83	12.72		
0:25:13	17.73	2.31	23.74	0.74	0.82	12.59		
0:25:44	17.23	2.44	27.31	0.91	1.1	16.98		
0:26:15	16.42	2.7	36.37	1.35	1.82	27.93	130	
0:26:46	16.51	2.71	42.23	1.28	2.06	31.71		
0:27:16	16.66	2.74	43.35	1.44	2.03	31.21	130	13
0:27:47	16.83	2.75	43.7	1.51	1.95	30.01		
0:28:18	16.84	2.75	43.8	1.46	1.95	30.03	135	
0:28:49	16.73	2.79	44.76	1.44	2.05	31.54		
0:29:20	16.8	2.76	45.59	1.38	2.05	31.53	134	13
0:29:50	16.84	2.78	48.76	1.39	2.17	33.38		
0:30:21	16.89	2.78	43.97	1.47	1.93	29.64	136	
0:30:52	16.75	2.81	46.77	1.56	2.13	32.76		
0:31:23	16.84	2.77	43.72	1.41	1.94	29.9	130	14
0:31:54	16.61	2.84	43.92	1.42	2.07	31.88		
0:32:24	16.63	2.82	44.3	1.58	2.08	32.04		
0:32:55	16.74	2.81	42.91	1.72	1.96	30.11		
0:33:26	16.79	2.81	29.06	1.21	1.31	20.1		
0:33:56	17	2.76	21.82	0.81	0.93	14.27		
0:34:27	17.26	2.59	23.02	0.47	0.91	14.02		
0:34:58	17.4	2.51	14.35	0.43	0.55	8.41		
0:35:29	17.7	2.35	14.03	0.64	0.49	7.48		
0:36:00	17.57	2.31	14.29	0.4	0.52	8.01		
0:36:30	17.57	2.34	12.6	0.41	0.46	7.05		
0:37:01	17.58	2.36	12.99	0.37	0.47	7.22		
0:37:32	17.56	2.31	17.05	0.41	0.62	9.59		
0:38:04	17.59	2.35	9.42	0.29	0.34	5.23		
0:38:34	18.13	2.01	10.76	0.37	0.32	4.99		
0:39:05	18.22	1.87	14.98	0.47	0.44	6.78		
0:39:35	18.18	1.99	19.03	0.5	0.56	8.65		
0:40:06	17.5	2.22	24.86	0.99	0.93	14.35		
0:40:37	17.15	2.34	29.2	1.22	1.22	18.72	145	
0:41:07	16.96	2.41	36.86	1.12	1.62	24.91	150	
0:41:38	17.02	2.44	42.4	1.37	1.83	28.09	152	
0:42:09	17.17	2.52	44.12	1.7	1.81	27.85	153	
0:42:40	17.12	2.62	45.01	1.73	1.86	28.6	158	
0:43:11	17.23	2.64	45.43	1.57	1.81	27.88		
0:43:41	17.03	2.77	43.8	1.46	1.84	28.35		
0:44:12	17.03	2.76	42.79	1.58	1.8	27.74		
0:44:43	16.79	2.88	43.12	1.8	1.93	29.7		
0:00:35	17.79	2.37	16.03	0.52	0.54	8.26		
0:01:06	17.71	2.33	13.6	0.5	0.47	7.25		
0:01:37	17.7	2.31	13.31	0.49	0.46	7.14		
0:02:08	17.49	2.37	16.85	0.73	0.63	9.66		

Table 62. Subject 173 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:02:39	17.55	2.33	25.38	0.82	0.93	14.32		
0:03:09	18.04	2.33	29.59	0.9	0.9	13.87		
0:03:40	17.27	2.64	36.43	1.35	1.44	22.1		
0:04:11	16.92	2.65	39.61	1.72	1.74	26.7		
0:04:42	16.6	2.67	40.83	1.51	1.95	30	139	
0:05:13	16.33	2.75	47.88	2	2.44	37.53		
0:05:43	16.6	2.75	51.09	1.89	2.43	37.38	152	13
0:06:14	16.69	2.77	51.01	1.89	2.36	36.35		
0:06:44	16.74	2.79	54.51	2.02	2.49	38.34	156	
0:07:15	16.87	2.79	53.77	1.92	2.37	36.47		
0:07:46	16.65	2.86	52.58	1.95	2.45	37.69	159	15
0:08:17	16.75	2.82	53.37	1.98	2.43	37.31		
0:08:48	16.75	2.83	53.47	1.98	2.43	37.43	160	
0:09:18	16.67	2.87	55.41	1.91	2.57	39.55		
0:09:49	16.75	2.88	52.72	1.76	2.39	36.76	160	16
0:10:20	16.6	2.95	50.36	1.87	2.37	36.46		
0:10:50	16.54	2.95	25.05	0.46	1.2	18.43		
0:11:21	16.57	2.9	10.47	0.23	0.5	7.65		
0:11:52	16.6	2.89	10.51	0.2	0.5	7.64		
0:12:23	16.53	2.94	10.53	0.2	0.5	7.76		

Table 63. Subject 214 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	17.42	2.18	20.59	0.82	0.8	10.33		
0:01:06	17.05	2.53	19.93	0.69	0.85	10.96	89	
0:01:37	16.38	2.69	22.4	0.83	1.13	14.68		7
0:02:08	16.05	2.72	23.53	0.76	1.28	16.66	88	
0:02:39	16.14	2.64	22.79	0.88	1.22	15.87		
0:03:09	16.05	2.71	23.53	1.02	1.28	16.66	85	
0:03:40	16.16	2.68	22.31	0.89	1.19	15.42		
0:04:11	16.06	2.71	24.45	0.98	1.33	17.28	86	7
0:04:42	16.21	2.67	24.06	0.86	1.27	16.43		
0:05:13	16.24	2.69	23.8	0.95	1.24	16.15	95	
0:05:44	16.34	2.72	24.31	1.1	1.24	16.08		7
0:06:15	16.32	2.72	26.13	1	1.34	17.35		
0:06:45	16.64	2.63	25.14	0.97	1.19	15.43	108	
0:07:16	16.3	2.81	26.57	1.21	1.36	17.65		
0:07:47	15.91	2.92	27.09	1.35	1.51	19.63	97	
0:08:17	15.94	2.9	27.27	1.14	1.51	19.63		9
0:08:49	15.93	2.89	28.47	1.24	1.59	20.56	101	
0:09:19	15.85	2.87	28.99	0.94	1.64	21.34		
0:09:50	15.91	2.88	27.63	1.11	1.55	20.06	106	9
0:10:20	15.96	2.83	28.98	1.26	1.61	20.86		
0:10:51	15.91	2.83	29.38	1.28	1.65	21.37	105	
0:11:22	15.86	2.87	27.31	1.05	1.54	20.04		
0:11:53	15.81	2.9	29.04	1.21	1.66	21.51	108	9
0:12:24	15.94	2.87	28.59	1.19	1.59	20.63		
0:12:55	15.96	2.86	31.73	1.06	1.75	22.76	111	
0:13:26	15.88	2.95	30.98	1.29	1.74	22.57		
0:13:56	15.9	2.94	33.12	1.66	1.85	24.01	115	
0:14:27	15.93	2.93	31.67	1.22	1.76	22.83		10
0:14:58	16.01	2.92	32.42	1.41	1.77	22.96	111	
0:15:29	15.9	2.93	31.6	1.32	1.77	22.91		
0:15:59	15.83	2.97	30.6	1.22	1.74	22.54		
0:16:30	15.83	2.97	30	1.2	1.7	22.07	113	11
0:17:01	15.76	2.96	33.1	1.23	1.91	24.76	118	
0:17:32	15.89	2.92	32.26	1.4	1.81	23.45	117	
0:18:02	15.93	2.97	33.28	1.33	1.84	23.93		
0:18:33	16.19	2.92	31.83	1.22	1.67	21.61	114	11
0:19:04	15.8	3.01	31.72	1.17	1.81	23.44		
0:19:34	15.95	2.97	37.88	1.52	2.09	27.09		
0:20:05	15.92	3.02	36.31	1.51	2.01	26.11	135	
0:20:36	15.39	3.28	38.92	1.77	2.39	31.05		
0:21:07	15.65	3.27	41.24	1.65	2.4	31.1	144	12
0:21:37	15.69	3.27	42.81	1.95	2.47	32.01		
0:22:08	15.68	3.3	42.88	1.72	2.47	32.09	145	
0:22:39	15.48	3.4	39.75	1.89	2.38	30.92		
0:23:10	15.53	3.38	40.87	1.57	2.43	31.54	150	12
0:23:41	15.59	3.33	45.2	2.15	2.66	34.5		

Table 63. Subject 214 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:12	15.74	3.27	45.56	2.17	2.6	33.73	148	
0:24:43	15.68	3.29	42.23	1.76	2.44	31.64		
0:25:13	15.69	3.25	41	2.05	2.37	30.68	151	
0:25:44	15.39	3.32	44.89	1.8	2.76	35.75		13
0:26:15	15.61	3.27	46.93	1.88	2.75	35.72		
0:26:46	16.03	3.15	52.35	2.38	2.81	36.45		
0:27:17	15.82	3.27	51.92	2.36	2.91	37.78	170	
0:27:47	15.72	3.34	57.54	2.4	3.29	42.69		
0:28:18	15.78	3.34	55.39	2.22	3.12	40.46	175	15
0:28:49	15.84	3.35	62.19	2.22	3.46	44.83		
0:29:20	15.95	3.29	60.38	2.24	3.28	42.53	176	
0:29:50	15.91	3.33	61.06	2.18	3.34	43.37		
0:30:21	15.82	3.4	60.11	2.4	3.35	43.43	177	16
0:30:52	15.71	3.47	59.43	2.29	3.39	43.91		
0:31:23	15.75	3.43	61.16	2.45	3.46	44.82	177	
0:31:54	15.7	3.45	62.24	2.31	3.55	46.07		
0:32:25	15.73	3.41	61.47	2.12	3.49	45.25		16
0:32:56	15.82	3.33	56.41	1.71	3.15	40.89		
0:33:27	17.06	2.59	7.57	0.13	0.32	4.15		

Table 64. Subject 221 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:35	17.29	2.01	17.6	0.29	0.72	9.59		
0:01:07	17.05	2.11	15.2	0.3	0.66	8.81		
0:01:37	17.18	1.98	3.78	0.12	0.16	2.13		
0:02:08	17.4	1.82	3.85	0.16	0.15	2.05		
0:02:40	18.18	1.4	3.84	0.19	0.12	1.6		
0:03:10	18.5	1.24	3.67	0.09	0.1	1.35		
0:03:40	19	0.99	8.67	0.3	0.19	2.53		
0:04:11	18.84	0.91	14.7	0.61	0.35	4.72		
0:04:42	17.27	1.68	15.13	0.41	0.63	8.45		
0:05:12	17.16	1.74	14.03	0.39	0.6	8.06		
0:05:43	17.05	1.81	11.75	0.45	0.52	6.95		
0:06:14	16.88	1.9	11.61	0.37	0.54	7.16		
0:06:45	16.76	1.9	11.28	0.3	0.54	7.18		
0:07:16	16.63	1.96	11.38	0.44	0.56	7.47		
0:07:47	16.44	2.01	14.4	0.6	0.74	9.9		
0:08:18	16.79	1.88	8.69	0.19	0.41	5.5		
0:08:48	16.57	1.99	12.16	0.47	0.61	8.09		
0:09:18	16.5	1.96	10.59	0.44	0.54	7.19		
0:09:50	16.62	1.94	10.1	0.36	0.5	6.66		
0:10:20	16.46	2.01	9.72	0.31	0.5	6.64		
0:10:51	16.62	1.94	13.95	0.38	0.69	9.2		
0:11:21	16.79	1.91	18.55	0.77	0.88	11.72		
0:11:52	17.1	1.91	14.81	0.31	0.64	8.59	124	
0:12:23	15.91	2.02	17.34	0.35	1.01	13.46		
0:12:54	15.34	2.18	18.09	0.44	1.17	15.67	122	10
0:13:26	15.3	2.2	18.67	0.39	1.22	16.3		
0:13:56	15.56	2.21	19.41	0.59	1.21	16.1	126	
0:14:26	15.77	2.19	19.31	0.47	1.15	15.34		
0:14:57	15.91	2.19	19.65	0.68	1.14	15.14	123	11
0:15:28	15.87	2.27	18.78	0.59	1.09	14.54		
0:15:58	15.95	2.22	18.05	0.49	1.03	13.77	125	
0:16:29	15.9	2.22	20.9	0.6	1.21	16.11		
0:17:00	15.88	2.24	19.33	0.47	1.12	14.97	125	11
0:17:31	15.99	2.26	19.89	0.55	1.12	14.99		
0:18:02	16	2.26	20.73	0.58	1.17	15.59		
0:18:33	15.95	2.26	25.01	0.76	1.43	19.02	139	
0:19:04	15.59	2.35	27.52	0.98	1.69	22.52		
0:19:34	15.54	2.44	27.36	0.88	1.69	22.56	140	12
0:20:05	15.61	2.49	28.23	1.23	1.72	22.88		
0:20:36	15.52	2.56	29.21	1.33	1.8	24.03	138	
0:21:06	15.68	2.58	28.35	1.05	1.69	22.57		
0:21:36	15.91	2.55	32.54	0.9	1.85	24.67	138	12
0:22:08	16.17	2.55	34.19	0.88	1.83	24.41		
0:22:39	16.24	2.51	32.88	0.84	1.73	23.13	137	
0:23:09	16.19	2.5	32.95	0.97	1.76	23.44		
0:23:40	16.23	2.5	34.63	1.05	1.83	24.43	140	12

Table 64. Subject 221 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:24:12	16.32	2.52	34.4	1.11	1.78	23.73	140	
0:24:42	16.34	2.45	33.39	1.11	1.72	22.97		
0:25:13	16.29	2.51	38.51	1.07	2.01	26.75	148	
0:25:44	16.3	2.55	38.89	1.39	2.02	26.9		
0:26:14	16.11	2.65	41.41	1.34	2.24	29.84	155	13
0:26:45	16.26	2.64	41.13	1.37	2.15	28.6		
0:27:15	16.29	2.64	39.3	1.16	2.03	27.12	152	
0:27:46	16.29	2.65	41.78	1.16	2.16	28.8		
0:28:17	16.3	2.63	41.73	1.23	2.16	28.77	152	13
0:28:48	16.26	2.64	41.78	1.16	2.18	29.04		
0:29:19	16.3	2.61	42.68	1.04	2.21	29.41	156	
0:29:50	16.29	2.64	44.05	1.13	2.28	30.41		
0:30:21	16.4	2.62	45.36	1.3	2.29	30.48	158	13
0:30:52	16.54	2.6	40.94	0.97	1.99	26.57		
0:31:22	16.31	2.62	36.94	1.06	1.91	25.4	157	
0:31:53	15.99	2.7	36.27	1.21	2.01	26.8		
0:00:36	15.93	3.1	47.91	2	2.64	35.24		
0:01:07	15.82	3.32	52.48	1.94	2.93	39.1	169	
0:01:37	15.96	3.45	56.46	2.17	3.04	40.5		
0:02:08	15.97	3.52	58.08	2.23	3.11	41.44	170	15
0:02:39	16.06	3.54	60.33	2.41	3.16	42.08		
0:03:10	16.08	3.55	62.23	2.07	3.24	43.2	176	
0:03:40	16.12	3.49	65.47	1.98	3.38	45.06		
0:04:11	16.12	3.48	63.61	2.19	3.29	43.83	176	17
0:04:42	16.16	3.46	64.18	2.14	3.29	43.81		
0:05:13	16.25	3.43	63.72	2.06	3.2	42.67	181	
0:05:43	16.12	3.45	64.25	2.29	3.33	44.34	181	
0:06:14	16.1	3.43	65.31	2.11	3.4	45.38		18
0:00:36	17.68	2.27	22.46	0.45	0.79	10.54		
0:01:06	17.09	2.45	28.49	0.75	1.2	16		
0:01:37	15.94	2.61	32.52	1.35	1.83	24.4		
0:02:08	15.69	2.74	37.9	1.35	2.24	29.89		
0:02:39	15.54	2.92	44.02	1.69	2.67	35.55		
0:03:09	15.48	3.14	55.75	2.32	3.38	45.1	182	
0:03:40	15.48	3.44	65.78	2.35	3.94	52.49		
0:04:11	15.92	3.49	67.85	2.42	3.68	49.04	188	18
0:04:42	15.92	3.57	69.45	2.24	3.75	50.02		
0:05:12	16.02	3.59	73.25	2.36	3.86	51.46	192	
0:05:43	16.16	3.62	76.43	2.07	3.89	51.86		
0:06:13	16.15	3.61	74.92	2.2	3.82	50.94	194	20
0:06:44	16.16	3.64	76.11	2.06	3.86	51.53		
0:07:15	16.23	3.51	81.92	1.82	4.12	54.93	199	
0:07:46	16.1	3.45	63.25	1.07	3.29	43.84		

Table 65. Subject 231 condition C.

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:00:36	18.85	1.7	13.35	0.36	0.29	4.74		
0:01:07	18.33	1.88	14.77	0.43	0.41	6.7	88	
0:01:38	18.08	1.93	15.91	0.64	0.49	7.99		
0:02:08	18.04	1.94	15.98	0.43	0.5	8.17	87	6
0:02:40	18.1	1.9	16.99	0.46	0.52	8.5		
0:03:10	18	1.95	16.23	0.71	0.52	8.41	93	
0:03:40	18	1.9	16.86	0.73	0.54	8.77		
0:04:12	18.09	1.87	16.17	0.67	0.5	8.14	94	6
0:04:42	18.13	1.88	16.46	0.51	0.5	8.16		
0:05:13	18.15	1.87	15.29	0.53	0.46	7.5	101	
0:05:44	18.05	1.88	16.87	0.54	0.53	8.61		
0:06:15	18.13	1.86	16.39	0.57	0.5	8.11	94	6
0:06:46	18.02	1.91	15.16	0.32	0.48	7.83		
0:07:16	18.07	1.86	17.86	0.5	0.56	9.06		
0:07:47	18.35	1.81	19.52	0.56	0.55	8.84	98	
0:08:17	17.7	2.03	20.49	0.53	0.73	11.83		
0:08:48	17.6	2.06	21.66	0.72	0.8	12.9	94	
0:09:19	17.58	2.06	22.37	0.72	0.83	13.43		7
0:09:50	17.56	2.06	22.13	0.85	0.83	13.39	100	
0:10:21	17.61	2.07	22.01	0.73	0.81	13.05		
0:10:51	17.62	2.06	22.04	0.69	0.8	13.04	103	7
0:11:22	17.63	2.06	22.1	0.79	0.8	13.01		
0:11:52	17.63	2.08	21.94	0.63	0.8	12.91	100	
0:12:23	17.83	2.04	22.18	0.58	0.75	12.17		
0:12:54	17.71	2.06	22.68	0.91	0.8	13.01	97	7
0:13:26	17.85	2.04	22.51	0.66	0.76	12.29		
0:13:56	17.79	2.08	21.96	0.71	0.75	12.21		
0:14:26	17.68	2.08	24	0.92	0.86	13.87	107	
0:14:57	17.49	2.18	23.97	0.65	0.91	14.69		
0:15:28	17.36	2.21	24.64	0.88	0.97	15.73	108	8
0:15:59	17.47	2.16	23.7	0.74	0.9	14.64		
0:16:30	17.29	2.24	25.93	0.79	1.04	16.89	109	
0:17:01	17.46	2.17	26.14	0.84	1	16.2		
0:17:32	17.53	2.16	24.8	0.83	0.93	15.03	106	
0:18:02	17.49	2.19	25.01	0.69	0.94	15.31		8
0:18:33	17.43	2.19	24.92	0.83	0.96	15.55	104	
0:19:03	17.48	2.21	26.33	0.91	1	16.17		
0:19:34	17.59	2.17	25.48	0.88	0.93	15.09	108	
0:20:05	17.57	2.18	25.74	0.86	0.95	15.33		8
0:20:37	17.64	2.16	24.3	0.57	0.87	14.15		
0:00:36	18.46	1.72	13.33	0.28	0.36	5.78		
0:01:06	18.15	2.01	12.8	0.44	0.38	6.21		
0:01:38	18.01	2.03	14.85	0.42	0.47	7.6		
0:02:08	18.13	1.97	15.78	0.46	0.48	7.74		
0:02:39	18.24	1.95	20.8	0.56	0.6	9.77		

Table 65. Subject 231 condition C (cont.).

Time h:m:s	O_2 %	CO_2 %	V_E (L/min)	V_T (L)	V_{O2} (L/min)	V_{O2} (mL/kg/min)	HR (bpm)	RPE
0:03:10	17.85	2.12	24.09	0.73	0.81	13.05		
0:03:41	17.11	2.24	26.88	0.66	1.14	18.51		
0:04:11	16.85	2.27	30.61	0.73	1.4	22.65	127	
0:04:41	16.71	2.37	33.6	0.96	1.59	25.71		
0:05:13	16.65	2.45	34.44	1.04	1.64	26.66	125	
0:05:44	16.81	2.46	33.78	0.94	1.54	24.98		13
0:06:14	16.73	2.6	36.61	1.05	1.7	27.5	128	
0:06:45	16.86	2.49	36.36	1.1	1.63	26.48		
0:07:17	16.92	2.51	37.01	1.19	1.64	26.51	131	
0:07:47	17.12	2.46	37.85	1.18	1.58	25.63		13
0:08:17	17.12	2.47	36.31	1.01	1.51	24.54	134	
0:08:48	17.07	2.45	34.25	0.93	1.45	23.51		
0:09:19	16.88	2.54	37.02	1.28	1.65	26.78	133	
0:09:49	17.1	2.47	36.1	1.09	1.52	24.58	136	13
0:10:21	16.98	2.5	34.9	1.2	1.52	24.59		
0:10:51	17.31	2.4	31.56	1.05	1.25	20.19		
0:11:22	17.57	2.31	27.93	0.82	1.02	16.5		
0:11:52	18.12	2.1	19.75	0.62	0.59	9.61		
0:12:23	18.12	2.12	17.54	0.84	0.53	8.53		
0:12:54	18.32	2.09	14.21	0.39	0.39	6.34		
0:13:25	18.35	2.02	13.7	0.42	0.37	6.06		
0:13:56	18.27	2.03	16.19	0.33	0.46	7.44		
0:14:27	18.31	2.03	22.6	0.63	0.63	10.22		
0:14:57	18.28	2.05	25.76	0.83	0.73	11.78		
0:15:28	17.54	2.28	31.6	0.93	1.17	18.91		
0:15:59	17.19	2.35	34.08	0.95	1.4	22.7	144	
0:16:29	16.99	2.42	38.35	1.24	1.67	27.03		
0:17:00	16.71	2.52	39.35	1.23	1.84	29.82	148	15
0:17:32	16.58	2.63	41.13	1.25	1.98	32.13		
0:18:02	16.76	2.64	41.98	1.2	1.92	31.18	151	
0:18:33	16.84	2.69	41.38	1.33	1.85	29.98		
0:19:04	16.85	2.69	43.04	1.35	1.92	31.08	156	
0:19:34	16.76	2.77	42.77	1.34	1.95	31.56		
0:20:05	16.91	2.69	44.08	1.22	1.93	31.3	157	
0:20:36	16.92	2.69	44.79	1.36	1.95	31.67		
0:21:07	16.94	2.68	44.2	1.34	1.92	31.09	157	15
0:21:38	16.9	2.68	43.86	1.22	1.93	31.22		
0:22:08	16.85	2.7	41.5	1.12	1.85	29.92		
0:22:40	17.14	2.55	9.07	0.13	0.37	6.06		

Appendix D Program Listing and Simulation

```
'**********************************************************
'***** Developed in Visual BASIC 6.0
'***** Developed by Karen M. Coyne
'***** Last modified 13MAY01
'**********************************************************
'***** Developed on a Pentium 133 MHz; Windows 95
'***** 64M RAM
'**********************************************************
'***** This program allows the user to examine the effects
'***** of a respirator mask on a person during physical
'***** activity. Default values are provided for all
'***** variables so that the program may be run without
'***** any user input. The program is run by clicking on
'***** the "Run Test" button.  Default input values may be
'***** changed by clicking on the appropriate button.
'**********************************************************
'***** Functions are defined first.  The main loop is found
'***** in the subroutine cmdRunTest_Click()
'**********************************************************

Public Function EtaMusc(sgExtW As Single)
    'determine gross muscle efficiency (EtaMusc) as
    'a function of external work rate (sgExtW)
    If sgExtW < 20.1 Then
        EtaMusc = sgExtW / 200
    ElseIf sgExtW < 159.3 Then
        EtaMusc = 0.1003 + 0.0006 * (sgExtW - 20.1)
    ElseIf sgExtW < 240 Then
        EtaMusc = 0.1839 + 0.0002 * (sgExtW - 159.3)
    Else
        EtaMusc = 0.2
    End If

End Function

Public Function MetM(sgSurface As Single, sgMass As Single, sgSpeed As Single, sgGrade
As Single, sgLdCarried)
    'Pandolf et al. (1977) equation for physiological work rate (MetM)
    'sgSpeed and sgGrade are treadmill speed and grade
    Dim sgWeight As Single 'weight of subject
    Dim sgWtCarried As Single 'total weight carried
    sgWeight = 9.81 * sgMass
    sgWtCarried = 9.81 * sgLdCarried
    MetM = 0.15 * sgWeight + 0.2 * (sgWeight + sgWtCarried) * (sgWtCarried / sgWeight) ^
2 + 0.102 * sgSurface * (sgWeight + sgWtCarried) * (1.5 * sgSpeed ^ 2 + 35 * sgSpeed *
sgGrade / 100) - (sgWeight + sgWtCarried) * sgSpeed * sgGrade / 100
End Function

Public Function RR(sgMinVol As Single, sgTidVol As Single)
```

```
        'determine respiratory rate (RR)
        'sgMinVol is minute ventilation
        'sgTidVol is tidal volume
        RR = sgMinVol / sgTidVol
    End Function

    Public Function VO2fastss(sgWin As Single)
        'determine the steady-state VO2
        'this is the ss for the fast component
        'VO2fastss = 0.002952 * sgWin 'original equaiton
        'sgWin is physiological work rate (W)
        VO2fastss = 0.0028 * sgWin + 0.4398
    End Function
    Public Function VO2Adj(sgVE As Single)
        'adjust VO2 based on decrease in VE with respirator
        'sgVE is minute ventilation; VO2 - oxygen consumption
        VO2Adj = 0.034 * sgVE + 0.4322
    End Function

    Public Function SinWR2(K1 As Single, K2 As Single, K3 As Single, c As Single, sgMinVol
    As Single, sgTid As Single, sgT As Single, sgV0 As Single, sgVr As Single, inFlag As
    Integer, inMask As Integer, sgEpsilon As Single, sgP As Single)
        'sinusoidal work rate equations
        'from Johnson,AT.1993.  How much work is expended for respiration?
        'Frontiers in Medical and Biological Engineering
        '5(4):265-287.
        'see the above reference for an explanation of the WR terms
        'K values are Rohrer coefficients, c compliance
        'sgVr is resting lung volume
        'sgEpsilon = 1 for inhalation; = -1 for exhalation
        'inMask=1 if mask worn; 0 otherwise
        'sgP: initial pressure to open exhalation valve
        Dim sgMaxF, sgMaxF2, sgMaxF3 As Single
        Dim WR1, WR2, WR3, WR4, WR5, WR6, WR7 As Single
        'WR terms are the work rate components - defined in Johnson, 1993
        Dim inIE As Integer, sgAA As Single, sgAX As Single
        Dim sgV0b As Single, sgVrb As Single, sgTidb As Single, sgMinVolb As Single
        'convert units from L and min to m^3 and sec
        sgV0b = sgV0 / 1000 'initial lung volume
        sgVrb = sgVr / 1000 'resting lung volume
        sgTidb = sgTid / 1000 'tidal volume
        sgMinVolb = (sgMinVol / 1000) / 60 'minute volume
        If inFlag = 0 Then
            inIE = 1        'inhalation
        Else
            inIE = -1       'exhalation
        End If
        pi = 3.1415962
        pi2 = pi * pi
```

```
    sgMaxF = sgMinVolb * sgEpsilon * pi / 2 'max flow
    sgMaxF2 = sgMaxF ^ 2
    sgMaxF3 = sgMaxF ^ 3
    sgAA = sgV0b * pi / (sgMaxF * sgT) + inIE
    sgAX = Sqr(sgAA * sgAA - 1)
    WR1 = K1 * sgMaxF2 / 2
    WR2 = 4 * K2 * sgMaxF3 / (3 * pi)
    WR3 = (K3 * sgMaxF * pi * (sgAA - sgAX)) / sgT
    WR4a = (2 * sgMaxF2 * sgT) / (pi2 * c)
    WR4b = inIE * sgTidb * (sgV0b - sgVrb) / (sgT * c)
    WR4 = WR4a + WR4b
    WR5 = 0
    WR6 = 0
    If inMask = 1 Then
        WR7 = sgP * sgTidb / sgT 'if a mask is worn, work to open valve
    Else
        WR7 = 0
    End If
    SinWR2 = WR1 + WR2 + WR3 + WR4 + WR5 + WR6 + WR7
End Function
Public Function HybridExp2WR(K1 As Single, K2 As Single, K3 As Single, c As Single,
sgMinVol As Single, sgVr As Single, inFlag As Integer, sgEpsilon As Single, sgV0 As
Single, sgTid As Single, sgT As Single, sgP As Single, inMask As Integer)
    'hybrid exponential work rate equations
    'from Johnson (1993)
    'K values are Rohrer coefficients, c compliance
    'sgVr is resting lung volume
    'sgEpsilon = 1 for inhalation; = -1 for exhalation
    'inMask=1 if mask worn; 0 otherwise
    'sgP: initial pressure to open exhalation valve
    Dim WR1, WR2, WR3, WR4, WR5, WR6, WR7 As Single
    Dim sgTau As Single, sgTR As Single, sgMT As Single, sgMTau As Single
    Dim sgMaxF As Single, sgMaxF2 As Single, sgMaxF3 As Single
    Dim sgExp8 As Single, sgExp16 As Single, sgExp24 As Single
    Dim sr As Single, cc As Single, L6 As Single, bb As Single
    Dim ss As Single, aa As Single, ep As Single, em As Single
    Dim b As Single, X1 As Single, X2 As Single
    Dim r1 As Single, r2 As Single, r As Single, L5 As Single
    Dim sgMinVolb As Single, sgV0b As Single, sgVrb As Single, sgTidb As Single
    Dim inIE As Integer
    'convert units from L and min to m^3 and sec
    sgMinVolb = (sgMinVol / 1000) / 60 'minute volume
    sgV0b = sgV0 / 1000 'initial lung volume
    sgVrb = sgVr / 1000 'resting volume
    sgTidb = sgTid / 1000 'tidal volume
    If inFlag = 0 Then
        inIE = 1 'inhalation
    Else
        inIE = -1 'exhalation
```

```
End If
sgTau = (K1 + K2 * sgMinVolb * sgEpsilon + K3 / (sgV0b + inIE * sgTidb / 2)) * c
sgTR = sgT / sgTau
sgExp8 = Exp(-0.8 * sgTR)
sgExp16 = sgExp8 ^ 2
sgExp24 = sgExp8 * sgExp16
'sgMaxF = sgMinVolb * sgEpsilon / (0.05 + (1 - sgExp8) / sgTR + 0.05 * sgExp8)
sgMaxF = sgTidb / (sgTau * (1 - sgExp8) + 0.05 * sgT * (1 + sgExp8))
sgMaxF2 = sgMaxF ^ 2
sgMaxF3 = sgMaxF ^ 3
sgMT = sgMaxF * sgT
sgMTau = sgMaxF * sgTau
WR1 = K1 * sgMaxF2 * ((1 + sgExp16) / 15 + (1 - sgExp16) / sgTR) / 2
WR2 = K2 * sgMaxF3 * ((1 + sgExp24) / 40 + (1 - sgExp24) / (3 * sgTR))
b = sgV0b / sgMT
ss = Sqr(20 * b)
aa = 2 - 2 * ss * Atn(1 / ss)
ep = (1 + sgExp8)
em = 1 - sgExp8
X1 = b + inIE * 0.05
X2 = X1 + inIE * em / sgTR
If X1 / X2 < 0 Then
    'nothing
Else
    L5 = Log(X1 / X2)
End If
bb = -inIE * em - L5 * sgTR * (X1 + inIE / sgTR)
a = X2 - inIE * 4.95 * sgExp8
r1 = inIE * 20 * a * sgExp8 + 100 * sgExp16
r2 = 2 * sgExp8
r = -r1
If r > 0 Then
    sr = Sqr(r)
    cc = (-2 * inIE * r1 / sr) * Atn(sgExp8 / sr) - inIE * r2
Else
    sr = Sqr(-r)
    L6 = inIE * Log((sr + sgExp8) / ((sr - sgExp8)))
    cc = (r1 * L6 / sr) - inIE * r2
End If
WR3 = K3 * sgMaxF * (aa + bb + cc) / sgT
'WR4a = sgMaxF2 / (sgT * c)
'WR4b1 = (sgT ^ 2) / 800
'WR4b2 = sgTau * (0.05 * sgT + sgTau) * (1 - sgExp8)
'WR4b3 = ((sgTau ^ 2) / 2) * (1 - sgExp16)
'WR4b4 = sgExp8 * ((sgT ^ 2) * (0.0025 + 0.00125 * sgExp8) + 0.05 * sgTau * sgT * (1 -
sgExp8))
'WR4b = WR4b1 + WR4b2 + WR4b3 + WR4b4
'WR4c = inIE * sgTidb * (sgV0b - sgVrb) / (sgT * c)
'WR4 = WR4a * WR4b + WR4c
```

```
    'WR4 below taken from respwork program summer 2000
    WR4 = sgTidb * (sgTidb / 2 + inIE * (sgV0b - sgVrb)) / (sgT * c)
    WR5 = 0
    WR6 = 0
    If inMask = 1 Then
        WR7 = sgP * sgTidb / sgT 'if a mask is worn, work to open valve
    Else
        WR7 = 0
    End If
    HybridExp2WR = WR1 + WR2 + WR3 + WR4 + WR5 + WR6 + WR7

End Function
Public Function FlowLim2WR(K1 As Single, K2 As Single, K3 As Single, c As Single, sgI
As Single, sgV0 As Single, sgMinVol As Single, sgTid As Single, sgEpsilon As Single,
inFlag As Integer, sgFRC As Single, sgT As Single, sgRV As Single, sgP As Single, inMask
As Integer, sgPm As Single, sgVC)
    'flow-limited hybrid exponential equations
    'from Johnson (1993)
    'K values are Rohrer coefficients, c compliance, sgI inertia
    'sgVr is resting lung volume
    'sgEpsilon = 1 for inhalation; = -1 for exhalation
    'inMask=1 if mask worn; 0 otherwise
    'sgP: initial pressure to open exhalation valve
    Dim WR1, WR2, WR3, WR4, WR5, WR6, WR7 As Single
    Dim sgTau As Single, sgTR As Single, sgExp8 As Single
    Dim sgExp16 As Single, sgMaxF As Single, sgMaxF2 As Single, sgMaxF3 As Single
    Dim sgMT As Single, sgMTau As Single, b As Single, ss As Single
    Dim aa As Single, a As Single, r1 As Single, r2 As Single
    Dim r As Single, sr As Single, cc As Single, L6 As Single
    Dim sgExp1 As Single, sgExp9 As Single, c1 As Single, c2 As Single
    Dim c3 As Single, c4 As Single, c5 As Single, c6 As Single
    Dim inIE As Integer, em As Single
    Dim sgV0b As Single, sgMinVolb As Single, sgRVb As Single
    Dim sgTidb As Single, sgFRCb As Single, sgVCb As Single
    'convert units from L and min to m^3 and sec
    sgMinVolb = (sgMinVol / 1000) / 60 'minute volume
    sgV0b = sgV0 / 1000 'initial lung volume
    sgVCb = sgVC / 1000 'vital capacity
    sgRVb = sgRV / 1000 'residual volume
    sgTidb = sgTid / 1000 'tidal volume
    sgFRCb = sgFRC / 1000 'functional residual capacity
    If inFlag = 0 Then
        inIE = 1 'inhalation
    Else
        inIE = -1 'exhalation
    End If
    sgTau = (K1 + K2 * sgMinVolb * sgEpsilon + K3 / (sgV0b + inIE * sgTidb / 2)) * c
    sgTR = sgT / sgTau
    em = 1 - Exp(8)
```

```
   sgExp8 = Exp(-0.8 * sgTR)
   sgExp16 = sgExp8 ^ 2
   sgExp24 = sgExp8 * sgExp16
   sgMaxF = sgMinVolb * sgEpsilon / (0.05 + (1 - sgExp8) / sgTR + 0.05 * sgExp8)
   sgMaxF2 = sgMaxF ^ 2
   sgMaxF3 = sgMaxF ^ 3
   sgMT = sgMaxF * sgT
   sgMTau = sgMaxF * sgTau
   WR1 = K1 * sgMaxF2 * (1 + sgExp16) / 30
   WR2 = K2 * sgMaxF3 * (1 + sgExp24) / 40
   b = sgV0b / sgMT
   ss = Sqr(20 * b)
   'ss = Sqr(20 * sgV0b) / sgMT
   aa = 2 - 2 * ss * Atn(1 / ss)
   a = b + inIE * 0.05 + inIE * (1 - sgExp8) / sgTR - inIE * 4.95 * sgExp8
   r1 = inIE * 20 * a * sgExp8 + 100 * sgExp16
   r2 = 2 * sgExp8
   r = -r1
   If r > 0 Then
      sr = Sqr(r)
      cc = (-2 * inIE * r1 / sr) * Atn(sgExp8 / sr) - inIE * r2
   Else
      sr = Sqr(-r)
      L6 = inIE * Log((sr + sgExp8) / ((sr - sgExp8)))
      cc = (r1 * L6 / sr) - inIE * r2
   End If
   'X = sgV0b / sgMT + inIE * 0.05
   'L5 = Log(X / (X + inIE * (1 - sgExp8) / sgTR))
   'bb = -inIE * (1 - sgExp8) - L5 * sgTR * (X + inIE / sgTR)
   sgV0b = sgRVb - inIE * (0.05 * sgMT * sgMTau)
   WR3 = K3 * sgMaxF * (aa + cc) / sgT
   'aa = sgMaxF * (sgFRCb - sgV0b + sgMaxF * sgT / 40) / (c * 20)
   'bb = sgMaxF * sgExp8 * (sgFRCb - sgV0b + sgMaxF * (sgT / 20 + sgTau * (1 - sgExp8))
+ sgMaxF * sgExp8 * sgT / 40) / (c * 20)
   'WR4 = aa + bb
   'WR4 = sgMaxF * sgT * (sgMaxF * (1 / 40 + sgExp8 / 20 + sgExp16 / 40 + sgExp8 * em /
sgTR) - sgTidb * (sgV0b - sgFRCb) * (1 + sgExp8) / sgT) / (20 * c)
   WR4 = (sgMaxF2 * sgT / (20 * c)) * (1 / 40 + sgExp8 / 20 + sgExp16 / 40 + (sgTau *
sgExp8 / sgT) * (1 - sgExp8)) - (sgV0b - sgFRCb) * (0.05 * sgT * sgVmax) * (1 + sgExp8) /
(c * sgT)
   kmc = c
   WR5 = sgI * sgMaxF2 * (1 - sgExp16) / (2 * sgT)
   sgExp1 = Exp(-0.1 * sgTR)
   sgExp9 = sgExp1 * sgExp8
   c1 = 0.145
   c2 = 0.306
   c3 = 100 * (0.1 * sgMT + 2 * sgMTau + sgRVb) / sgVCb
   c4 = -100 * sgMTau / (sgExp1 * sgVCb)
   c5 = c1 * sgMaxF / sgExp1
```

```
    c6 = c2 * sgMaxF / sgExp1
    a = c3 + c4 * sgExp9
    b = c3 + c4 * sgExp1
    WR6 = (sgMaxF * sgTau / sgT) * (4325.651 * (1 - sgExp8) + (11703.94 / (2 * sgVCb)) *
sgTau * sgMaxF * (1 - sgExp16))
      'WR6 is pmax*flow during the flow-limited portion of the waveform
    If inMask = 1 Then
      WR7 = 0.05 * sgP * sgMaxF * sgT * (1 + Exp8) 'if a mask is worn, work to open valve
    Else
      WR7 = 0
    End If
    FlowLim2WR = WR1 + WR2 + WR3 + WR4 + WR5 + WR6

End Function

Public Function Te(sgRPD As Single)
    'exhalation time (Te)as a function of respiratory period(sgRPD)
    Te = 0.6176 * sgRPD - 0.2145
End Function
Public Function Ti(sgRPD As Single)
    'inhalation time (Ti)as a function of respiratory period (sgRPD)
    Ti = sgRPD - (0.6176 * sgRPD - 0.2145)
End Function

Public Function Trap3WR(K1 As Single, K2 As Single, K3 As Single, c As Single, sgVr As
Single, sgP As Single, inMask As Integer, sgTidal As Single, sgT As Single, sgV0 As Single,
inFlag As Integer, sgMinVol As Single, sgEpsilon As Single)
    'trapezoidal work rate equations
    'from Johnson (1993)
    'K values are Rohrer coefficients, c compliance
    'sgVr is resting lung volume
    'sgEpsilon = 1 for inhalation; = -1 for exhalation
    'inMask=1 if mask worn; 0 otherwise
    'sgP: initial pressure to open exhalation valve
    Dim sgVmax As Single
    Dim WR1, WR2, WR3, WR4, WR7 As Single
    Dim s As Single, L2 As Single, q As Single, L2a As Single
    Dim q1 As Single, p1 As Single, p As Single, L3 As Single
    Dim sgV0b As Single, sgVrb As Single, sgTidalb As Single
    Dim inIE As Integer, sgMinVolb As Single
    'convert units from L and min to m^3 and sec
    sgMinVolb = (sgMinVol / 1000) / 60 'minute volume
    sgV0b = sgV0 / 1000 'initial lung volume
    sgVrb = sgVr / 1000 'resting volume
    sgTidalb = sgTidal / 1000 'tidal volume
    If inFlag = 0 Then
      inIE = 1
    Else
      inIE = -1
```

```
    End If
    pi = 3.14
    'sgVmax = sgTidalb / (0.825 * sgT)
    sgVmax = sgMinVolb * sgEpsilon / 0.825
    WR1 = 0.730556 * K1 * sgVmax ^ 2
    WR2 = 0.8129416 * K2 * sgVmax ^ 3
    b = sgV0b / (sgVmax * sgT)
    ss = Sqr(20 * b)
    aa = 2 - 2 * ss * Atn(1 / ss)
    q1 = inIE * 0.4166667 * b + 1.020833
    q2 = 0.3333333
    q3 = 0.8333333
    q = -q1
    If q > o Then
        sq = Sqr(q)
        bb = (2 * q1 / sq) * (Atn(1.010417 / sq) - Atn(0.9270833 / sq)) - inIE * q2
    Else
        sq = Sqr(-q)
        L2a = Abs((sq + 1) * (sq - q3) / ((sq - 1) * (sq + q3)))
        L2 = inIE * Log(L2a)
        bb = q1 * L2 / sq - inIE * q2
    End If
    p1 = inIE * 16.66667 * b + 13.75
    p2 = 1.666667
    p = -p1
    If p > 0 Then
        sp = Sqr(p)
        cc = (-inIE * 2 * p1 / sp) * Atn(q3 / sp) - inIE * p2
    Else
        sp = Sqr(-p)
        L3 = inIE * Log(Abs((sp + q3) / (sp - q3)))
        cc = p1 * L3 / sp - inIE * p2
    End If
    WR3 = K3 * sgVmax * (aa + bb + cc) / sgT
    If inFlag = 0 Then
        WR4 = 0.3403343 * (sgVmax ^ 2 * sgT / c) + sgTidalb * (sgV0b - sgVrb) / (sgT * c)
    Else
        WR4 = 0.3403343 * (sgVmax ^ 2 * sgT / c) - sgTidalb * (sgV0b - sgVrb) / (sgT * c)
    End If
    If inMask = 1 Then
        WR7 = sgP * sgTidalb / sgT 'if a mask is worn, work to open valve
    Else
        WR7 = 0
    End If
    Trap3WR = WR1 + WR2 + WR3 + WR4 + WR7
End Function
Public Function V0i(sgVit As Single, sgRes As Single, sgTid As Single, sgFRC As Single,
sgW As Single)
    'determine the starting volume for inhalation
```

```
    Dim a As Single, b As Single, c As Single
    Dim sgResb As Single, sgVitb As Single, sgFRCb As Single, sgTidb As Single
    Dim V0itemp As Single
    'convert from L to m^3
    sgResb = sgRes / 1000 'residual volume
    sgVitb = sgVit / 1000 'vital capacity
    sgFRCb = sgFRC / 1000 'functional residual capacity
    sgTidb = sgTid / 1000 'tidal volume
    a = 6.39
    b = -a * (sgTidb + 2 * sgResb) + 2 * sgVitb
    c = a * sgResb * (sgResb + sgTidb) - sgVitb * (sgTidb + 2 * sgResb + sgVitb)
    V0itemp = (-b + (b * b - 4 * a * c) ^ 0.5) / (2 * a)
    If V0itemp < sgResb Then
        V0itemp = sgResb
    End If
    'for low work rates V0i is FRC
    'for light it is midway between calculated volume and FRC
    If sgW < 5 Then
        V0i = sgFRC '* 1000 'convert back to L
    Else
        If sgW < 35 Then
            V0i = (((sgW - 5) * V0itemp + (35 - sgW) * sgFRC) / 30) * 1000 'convert back to L
        Else
            V0i = V0itemp * 1000
        End If
    End If
End Function

Public Function AT(sgMax As Single)
    'determine anaerobic threshold (AT)
    'sgMax:maximum oxygen consumption (mL/kg/min)
    AT = 0.8624 * sgMax - 7.1585 'ml/kg/min
End Function
Public Function Vminss(sgPerc As Single, sgMax As Single)
    'determine steady-state minute ventilation (Vminss)
    'sgPerc is percent of vo2max
    'sgMax is vo2max (L/min)
    Dim sgVEmax As Single 'minute ventilation
    Dim sgVEPercMax As Single '% of max VE
    sgVEmax = 20.01 * sgMax + 27.855 'L/min
    sgVEPercMax = 0.0095 * (sgPerc * sgPerc) - 0.133 * sgPerc + 17.153 '% eg 80%
    Vminss = sgVEPercMax * sgVEmax / 100 'L/min
End Function
Public Function VERes(sgPerc As Single, sgInh As Single, sgExh As Single)
    'determine change in VE due to added resistance (VERes)
    'sgPerc: % of vo2max
    'sgInh and sgExh are inhalation and exhalation resistances
    'sgInh and sgExh (cmH2O/L/s)
    If sgPerc < 30 Then 'below 30%VO2max
```

```
        VERes = -0.0037 * sgInh - 0.0223 * sgExh
    Else
        If sgPerc < 40 Then 'between 30 and 40%VO2max
            VERes = -0.0018 * sgInh - 0.0206 * sgExh
        Else
            If sgPerc < 50 Then 'between 40 and 50%VO2max
                VERes = -0.0065 * sgInh - 0.0469 * sgExh
            Else
                If sgPerc < 80 Then 'between 50 and 80%VO2max
                    VERes = -0.0156 * sgInh - 0.0846 * sgExh
                Else 'above 80%VO2max
                    VERes = -0.0454 * sgInh - 0.0967 * sgExh
                End If
            End If
        End If
    End If
End Function
Public Function VEVD(sgPerc As Single, sgVD As Single)
    'determine change in VE due to added dead space (VEVD)
    'sgPerc - %VO2max
    'sgVD - dead volume
    Dim VEchange As Single, sgFract As Single
    'VEchange - change in VE due to VD (temporary variable)
    sgFract = sgPerc / 100 '%VO2max expressed as decimal
    VEchange = 0.170432 * sgVD - 0.00681 - ((sgFract - 0.15) / 0.15) * (1.8 / 60)
    If VEchange < 0 Then 'no decreases in VE due to VD
        VEVD = 0
    Else
        VEVD = VEchange
    End If
End Function


Public Function VTidss(sgPerc As Single, sgMax As Single)
    'determine steady-state tidal volume (VTidss)
    'sgPerc - %VO2max
    'sgMax - VO2max (L/min)
    Dim sgVTmax As Single 'maximum tidal volume
    Dim sgVTPercMax As Single '% of max tidal volume
    sgVTPercMax = 0.9987 * sgPerc - 1.6809
    sgVTmax = 0.3864 * sgMax + 0.6416 'L
    VTidss = sgVTPercMax * sgVTmax / 100 'L
End Function
Public Function VTRes(sgPerc As Single, sgInh As Single, sgExh As Single)
    'determine change in tidal volume with added resistance (VTRes)
    If sgPerc < 30 Then 'less than 30%VO2max
        VTRes = 0
    Else
        If sgPerc < 40 Then 'between 30 and 40%VO2max
```

```
         VTRes = 0.0092 * sgInh + 0.208 * sgExh
      Else
         If sgPerc < 50 Then 'between 40 and 50%VO2max
            VTRes = 0
         Else
            If sgPerc < 80 Then 'between 50 and 80%VO2max
               VTRes = 0
            Else 'greater than 80%VO2max
               VTRes = -0.0162 * sgInh + 0.0746 * sgExh
            End If
         End If
      End If
   End If

End Function
Public Function VTVD(sgPerc As Single, sgVD As Single)
   'determine the change in tidal volume with added dead space (VTVD)
   'sgPerc - %VO2max
   'sgVD - dead volume (L)
   Dim VTchange As Single 'temporary variable change in VT with VD
   Dim sgFract As Single '%VO2max in decimal form
   sgFract = sgPerc / 100
   If sgPerc < 15 Then 'below 15%VO2max
      VTchange = 0.7468 * sgVD - 0.08445
   Else
      If sgPerc < 30 Then 'between 15 and 30%VO2max
         VTchange = 0.9933 * sgVD - 0.2537
      Else 'over 30%VO2max
         VTchange = 0.195 + 0.2517 * sgVD - 0.4256 * sgFract
      End If
   End If
   If VTchange < 0 Then
      VTVD = 0 'no decreased in VT due to VD
   Else
      VTVD = VTchange
   End If

End Function
Public Function O2Def(sgAdj As Single, sgSS As Single)
   'find oxygen deficit (L/min)
   'sgAdj - vo2 adjusted for resistance and dead volume of mask
   'sgSS - vo2 required by the activity
   O2Def = sgSS - sgAdj
End Function


Private Sub cmdMainExit_Click()
   'button on form main
   'click on this button to terminate the program
```

```
    End
End Sub

Public Sub cmdRunTest_Click()
    'button on form main
    'click on this button to run the program
    Dim I As Integer 'counter
    'declare metabolic variables
    Dim sgMetM As Single 'physiological work rate, W
    'declare general variables
    Dim sgSubjMass As Single  'subject mass, kg
    Dim sgSubjHt As Single  'subject ht, cm
    Dim inSubjAge As Integer  'subject age,yr
    Dim sgBMI 'body mass index
    Dim sgGender As Single
    Dim inFitness As Integer  'fitness level
    'declare thermal variables
    Dim sgRestCoreTemp As Single 'resting core temp,C
    Dim sgTerrain As Single  'terrain coefficient
    Dim stTerrain As String 'terrain name
    'declare respiratory variables
    Dim sgK1aw As Single 'Rohrer coefficients
    Dim sgK2aw As Single 'aw is airways
    Dim sgK3aw As Single
    Dim sgK1Iaw As Single 'inhalation K1 airways coefficient
    Dim sgK2Iaw As Single 'inhalation K2 airways coefficient
    Dim sgK3Iaw As Single 'inhalation K3 airways coefficient
    Dim sgK1Eaw As Single 'exhalation K1 airways coefficient
    Dim sgK2Eaw As Single 'exhalation K2 airways coefficient
    Dim sgK3Eaw As Single 'exhalation K3 airways coefficient
    Dim sgK1I As Single 'total inhalation K1 coefficient
    Dim sgK2I As Single 'total inhalation K2 coefficient
    Dim sgK3I As Single 'total inhalation K3 coefficient
    Dim sgK1E As Single 'total exhalation K1 coefficient
    Dim sgK2E As Single 'total exhalation K2 coefficient
    Dim sgK3E As Single 'total exhalation K3 coefficient
    Dim sgCompliance As Single 'compliance value for Rohrer equation
    Dim sgInertia As Single 'inertia value for Rohrer equation
    Dim sgRestVO2 As Single 'resting VO2
    Dim sgVO2max As Single 'max oxygen consumption
    Dim sgRelVO2max As Single 'VO2max in ml/kg/min
    Dim sgAbsVO2max As Single  'VO2max in L/min
    'Dim inVO2maxTime As Long 'time variable for later
    Dim sgVO2Percent As Single '%VO2max
    Dim sgVO2Fract As Single '%VO2max in decimal form
    Dim sgVitCap As Single 'lung vital capacity, L
    Dim sgResVol As Single 'lung residual volume, L
    Dim sgVrest As Single 'resting volume set = FRC
    Dim sgFuncResCap As Single 'functional residual capacity
```

```
Dim sgV0e As Single 'initial volume for exhalation
Dim sgV0i As Single 'initial volume for inhalation
Dim sgVERadj As Single 'VE adjustment for resistance
Dim sgVTRadj As Single 'VT adjustment for resistance
Dim sgVEVDadj As Single 'VE adjustment for dead space
Dim sgVTVDadj As Single 'VT adjustment for dead space
Dim sgVEadj As Single 'VE adjusted for resistance and dead volume
Dim sgVTadj As Single 'VT adjusted for resistance and dead volume
Dim sgVO2adj As Single 'VO2 adjusted for resistance and dead volume
Dim sgVTss As Single 'steady-state VT, L
Dim sgVEss As Single 'steady-state VE, L/min
Dim sgVO2ss As Single 'steady-state VO2, L/min
Dim sgRelAnThresh As Single 'anaerobic threshold in ml/kg/min
Dim sgAbsAnThresh As Single 'anaerobic threshold in L/min
Dim sgRespRate As Single 'respiratory rate
Dim sgTexp As Single 'exhalation time, sec
Dim sgTinsp As Single 'inhalation time, sec
Dim sgRespAddRinh As Single 'added lung resistance
Dim sgRespAddRexh As Single 'added lung resistance
Dim sgRespAddVD As Single 'added lung dead volume
Dim sgEpsilonE As Single 'dimensionless conversion between Texp and Tinsp
Dim sgEpsilonI As Single 'conversion between Texp and Tinsp
Dim sgRespPeriod As Single 'respiratory period, sec
Dim sgRespWRexh As Single 'exh work rate for resp,W
Dim sgRespWRinh As Single 'inh work rate for resp,W
Dim sgRespWR As Single 'total resp work rate,W
Dim sgRespWexh As Single 'exh work, N m
Dim sgRespWinh As Single 'inh work, N m
Dim sgRespW As Single 'total resp work, N m
Dim sgPmax As Single 'max lung pressure
Dim sgRespMuscEff As Single 'resp muscle efficiency
'declare test parameters
Dim sgEnvirTemp As Single 'ambient temp, C
Dim sgRelHum As Single 'relative humidity, %
Dim sgExtWorkRate As Single 'external work rate, W
Dim sgTreadSpeed As Single 'treadmill speed, m/s
Dim sgTreadGrade As Single 'treadmill grade, %
Dim sgLoad As Single 'load carried, kg
Dim sgTotalMass As Single 'load + subjmass + mask mass
Dim sgTotalLoad As Single 'load + mask mass, kg
Dim sgPhysWorkRate As Single 'physiological work rate, W
Dim sgStepRate As Single 'step/min
'declare respirator parameters
Dim inRespirator As Integer 'resp worn if > 0
Dim sgEccentricity As Single 'for later use
Dim sgMaskRinh As Single 'inh resistance of mask, cmH2O/L/s
Dim sgMaskRexh As Single 'exh resistance of mask, cmH2O/L/s
Dim sgMaskVD As Single 'dead volume of mask, L
Dim sgMaskMass As Single 'mass of mask, kg
```

```
    Dim sgMaskP As Single 'pressure to open exh valve
    Dim sgDeltaVD As Single 'change in dead volume
    'declare other variables
    Dim sgGravity As Single '9.81 m/s^2
    Dim sgMuscEff As Single 'gross muscular efficiency
    Dim myfilename As String 'file name for data
    Dim mydate As String 'date
    Dim mytime As String 'time
    Dim stdummy1 As String 'used for printing to myfile
    Dim stdummy2 As String 'used for printing to myfile
    Dim inWorkFlag As Integer 'flag for which work rate equation to use
    Dim sgPerfTime As Single 'performance time, min
    Dim sgMaxDeficit As Single 'max O2 deficit
'***********************************************
    inWorkFlag = 0 'initialize
    mydate = Date
    mytime = Time
    sgMaxDeficit = 4.03 'L, taken from Bearden and Moffatt (2000)
    sgGravity = 9.81
    sgMaskP = 59.93 'pressure to open the exhalation valve;from M17 mask
'**************************************************
'write start conditions to file
'**************************************************
     myfilename = "c:\PhD\Program\Output Files\" & frmMain.txtstartfile.Text
     Open myfilename & "init" For Output Access Write As #1
     Open myfilename & "resp1" For Output Access Write As #3
     Print #1, "Start Conditions File"
     Print #1, "Trial conducted: "; mydate, mytime
     Print #1,
"************************************************************************"
     Print #3, "Respiratory Data #1"
     Print #3, "Trial conducted: "; mydate, mytime
     Print #3,
"************************************************************************"
'*****************************************************************
'get values for variables from the forms and write to file
'*****************************************************************
'these variables are on the form SetGenParams
    sgSubjMass = frmSetGenParams.txtSubjMass.Text
    sgSubjHt = frmSetGenParams.txtSubjHt.Text / 100
    sgBMI = sgSubjMass / (sgSubjHt ^ 2)
    sgSubjAge = frmSetGenParams.txtSubjAge.Text
    If frmSetGenParams.optFemale.Value = True Then
       sgGender = 0.85
       stdummy1 = "Female"
    Else
       sgGender = 1
       stdummy1 = "Male"
    End If
```

```
If frmSetGenParams.optUntrained.Value = True Then
   inFitness = 0
   stdummy2 = "Untrained"
Else
   If frmSetGenParams.optTrained.Value = True Then
      inFitness = 1
      stdummy2 = "Trained"
   Else
      inFitness = 2
      stdummy2 = "Highly Untrained"
   End If
End If
'write general parameters to file
 Print #1, "Subject Characteristics"
 Print #1, "----------------------"
 Print #1, "Mass (kg)", sgSubjMass
 Print #1, "Height (m)", sgSubjHt
 Print #1, "Age (yr)", sgSubjAge
 Print #1, "Gender", stdummy1
 Print #1, "Fitness", stdummy2
'*********************************************
'get thermal values
'*********************************************
sgRestCoreTemp = frmSetThermParams.txtRestCoreTemp.Text
'get terrain coefficient for use in Pandolf physiological
'work rate equation
If frmSetThermParams.optT1.Value = True Then
   sgTerrain = 1#
ElseIf frmSetThermParams.optT2.Value = True Then
   sgTerrain = 1.1
ElseIf frmSetThermParams.optT3.Value = True Then
   sgTerrain = 1.1 + 0.1 * frmSetThermParams.txtDepth.Text
ElseIf frmSetThermParams.optT4.Value = True Then
   sgTerrain = 1.2
ElseIf frmSetThermParams.optT5.Value = True Then
   sgTerrain = 1.5
ElseIf frmSetThermParams.optT6.Value = True Then
   sgTerrain = 1.8
ElseIf frmSetThermParams.optT7.Value = True Then
   sgTerrain = 2.1
End If
'write thermal parameters to file
 Print #1,
"*****************************************************************"
 Print #1, "Thermal Inputs"
 Print #1, "---------------------"
 Print #1, "Core Temp", , sgRestCoreTemp
 Print #1, "Terrain Factor", sgTerrain
'*********************************************
```

```
'*****  get respiratory system values
'*************************************************
If frmSetRespParams.optMaxL.Value = True Then
   sgAbsVO2max = frmSetRespParams.txtVO2Max.Text
   sgRelVO2max = sgAbsVO2max * 1000 / sgSubjMass
Else
   sgRelVO2max = frmSetRespParams.txtVO2Max.Text
   sgAbsVO2max = sgRelVO2max * sgSubjMass / 1000
End If
sgVitCap = frmSetRespParams.txtVC.Text
sgResVol = frmSetRespParams.txtRV.Text
sgFuncResCap = frmSetRespParams.txtFRC.Text
sgRespMuscEff = frmSetRespParams.txtRespMuscEff.Text
sgRespAddRinh = frmSetRespParams.txtAddInspR.Text
sgRespAddRexh = frmSetRespParams.txtAddExpR.Text
sgRespAddVD = frmSetRespParams.txtAddVD.Text
'write respiratory parameters to file
Print #1,
"************************************************************************"
Print #1, "Respiratory Inputs"
Print #1, "------------------"
Print #1, "VO2 max (L/min)", , sgAbsVO2max
Print #1, "VO2max (mL/kg/min)", , sgRelVO2max
Print #1, "Vital Capacity (L)", , sgVitCap
Print #1, "Residual Volume (L)", , sgResVol
Print #1, "Functional Residual Capacity (L)", sgFuncResCap
Print #1, "Resp. Musc. Eff. (%)", , sgRespMuscEff
Print #1, "Additional Resp. Res. Inh. (cmH20/L/s)", sgRespAddRinh
Print #1, "Additional Resp. Res. Exhh. (cmH20/L/s)", sgRespAddRexh
Print #1, "Additional Resp. Dead Vol. (L)", sgRespAddVD
'************************************************
'get respirator information
'************************************************
'eccentricity - respirator mass not evenly distributed on head
sgEccentricity = frmSelectRespirator.txtEccentricity.Text
If frmSelectRespirator.optM17.Value = True Then 'M17 selected
   stdummy1 = "M17"
   inRespirator = 1 'respirator worn
   sgMaskRinh = 3.4
   sgMaskRexh = 1.3
   sgMaskVD = 350 / 1000 'L
   sgMaskMass = 1 * sgEccentricity
Else
   If frmSelectRespirator.optM40.Value = True Then
      'M40 selected
      stdummy1 = "M40"
      inRespirator = 1 'respirator worn
      sgMaskRinh = 3.17
      sgMaskRexh = 1.69
```

```
            sgMaskVD = 300 / 1000 'L
            sgMaskMass = 0.7 * sgEccentricity
        Else
            If frmSelectRespirator.optOther.Value = True Then
                'other respirator selected
                'user sets resistance, dead volume, and mass
                stdummy1 = "Other"
                inRespirator = 1 'respirator worn
                sgMaskRinh = frmSelectRespirator.txtRinh.Text
                sgMaskRexh = frmSelectRespirator.txtRexh.Text
                sgMaskVD = frmSelectRespirator.txtRVD.Text / 1000 'L
                sgMaskMass = frmSelectRespirator.txtRMass.Text * sgEccentricity
            Else
                If frmSelectRespirator.optNone.Value = True Then
                    stdummy1 = "None"
                    inRespirator = 0 'respirator not worn
                    sgMaskRinh = 0
                    sgMaskRexh = 0
                    sgMaskVD = 0
                    sgMaskMass = 0
                End If
            End If
        End If
      End If
    'print respirator information to file
    Print #1,
"***********************************************************************"
    Print #1, "Respirator Selected"
    Print #1, "-------------------"
    Print #1, stdummy1
    If inRespirator = 1 Then
        Print #1, "Mask Inh. Res. (cmH20/L/s)", sgMaskRinh
        Print #1, "Mask Exh. Res. (cmH20/L/s)", sgMaskRexh
        Print #1, "Mask Dead Vol. (L)", sgMaskVD
        Print #1, "Mask Mass (kg)", sgMaskMass
    End If
    '**************************************************
    'get test values
    '**************************************************
    sgEnvirTemp = frmSetTestParams.txtEnvirTemp.Text
     sgLoad = frmSetTestParams.txtLoad.Text
     sgRelHum = frmSetTestParams.txtRelHum.Text
     'write test parameters to file
     Print #1,
"***********************************************************************"
     Print #1, "Test Inputs"
     Print #1, "-----------"
     Print #1, "Environ. Temp.(C)", sgEnvirTemp
     Print #1, "Rel. Humidity (%)", sgRelHum
```

```
        Print #1, "Load Carried (kg)", sgLoad
        'determine equation to use for external work rate calculation
        If frmSetTestParams.optExtWR.Value = True Then
          sgExtWorkRate = frmSetTestParams.txtExtWR.Text
          inWorkFlag = 1
          Print #1, "External Work Rate (W)", sgExtWorkRate
          If inRespirator = 1 Then
            sgExtWorkRate = sgExtWorkRate * (1 + (sgMaskMass + sgLoad) / sgSubjMass)
            Print #1, "Ext. WR Adjusted for Total Load (W)", sgExtWorkRate
          End If
        Else
          If frmSetTestParams.optTreadmill = True Then
            sgTreadSpeed = frmSetTestParams.txtSpeed.Text
            sgTreadGrade = frmSetTestParams.txtGrade.Text
            sgExtWorkRate = (sgSubjMass + sgLoad + sgMaskMass) * sgGravity *
    sgTreadSpeed * sgTreadGrade / 100
            Print #1, "Treadmill Speed (m/s)", sgTreadSpeed
            Print #1, "Treadmill Grade (%)", sgTreadGrade
            Print #1, "Ext. WR Adjusted for Total Load (W)", sgExtWorkRate
            inWorkFlag = 2
          Else
            If frmSetTestParams.optBike = True Then
              sgCadence = frmSetTestParams.txtCadence
              sgBikeLoad = frmSetTestParams.txtBikeLoad
              sgBikeDistance = frmSetTestParams.txtBikeDistance
              sgExtWorkRate = sgCadence * sgBikeLoad * sgBikeDistance * sgGravity / 60
              Print #1, "External Work Rate (W)", sgExtWorkRate
              Print #1, "Cadence", sgCadence
              Print #1, "Bike Load (kg)", sgBikeLoad
              Print #1, "Bike Distance per rev. (m)", sgBikeDistance
            Else
              If frmSetTestParams.optStep = True Then
                sgStepHt = frmSetTestParams.txtStepHt
                sgStepRate = frmSetTestParams.txtStepNum / 60
                sgExtWorkRate = sgStepHt * (sgSubjMass + sgLoad + sgMaskMass) *
  sgStepRate * sgGravity
                Print #1, "Ext. WR Adjusted for Total Load (W)", sgExtWorkRate
                Print #1, "Step Height (m)", sgStepHt
                Print #1, "Step Rate (steps/min)", sgStepRate
              End If
            End If
          End If
        End If
        Close #1 'close file with initial parameter values
'********************************************
    sgMuscEff = EtaMusc(sgExtWorkRate) 'gross muscle efficiency
    sgTotalMass = sgSubjMass + sgLoad + sgMaskMass 'total mass
    sgTotalLoad = sgLoad + sgMaskMass 'total mass carried
    'If (sgTreadGrade = 0) And inWorkFlag = 2 Then
```

```
If inWorkFlag = 2 Then 'treadmill work selected
    sgPhysWorkRate = MetM(sgTerrain, sgSubjMass, sgTreadSpeed, sgTreadGrade,
sgTotalLoad)
    frmMain.txtPandolf.Text = "Pandolf used"
Else
    If sgExtWorkRate = 0 Then
        sgPhysWorkRate = 105 'basal metabolic rate, W
    Else
        sgPhysWorkRate = sgExtWorkRate / sgMuscEff
    End If
End If
If sgPhysWorkRate < 105 Then
    sgPhysWorkRate = 105
End If
If (inRespirator > 0) And (inWorkFlag = 2) Then
    'respirator is worn; treadmill work selected
    sgPhysWorkRate = sgPhysWorkRate * (1 + (sgMaskMass + sgLoad) / sgSubjMass)
End If
'determine the vo2 required by the activity
sgVO2ss = VO2fastss(sgPhysWorkRate) 'L/min
sgVO2Fract = sgVO2ss / sgAbsVO2max
sgVO2Percent = sgVO2Fract * 100
'determine the anaerobic threshold
sgRelAnThresh = AT(sgRelVO2max)  'ml/kg/min
sgAbsAnThresh = sgRelAnThresh * sgSubjMass / 1000
'determine steady-state values for minute volume and tidal volume
sgVEss = Vminss(sgVO2Percent, sgAbsVO2max) 'L/min
sgVTss = VTidss(sgVO2Percent, sgAbsVO2max) 'L
If inRespirator = 0 Then
    'respirator not worn; no need to adjust parameters
    'for external resistance and dead volume
    sgVEadj = sgVEss
    sgVTadj = sgVTss
    sgVO2adj = sgVO2ss
Else
    'respirator worn; determine the changes in minute volume
    'and tidal volume for resistance and dead volume
    'determine the VE and VT with these changes
    sgVERadj = VERes(sgVO2Percent, sgMaskRinh, sgMaskRexh) * 60 'L/min
    sgVTRadj = VTRes(sgVO2Percent, sgMaskRinh, sgMaskRexh) 'L
    sgVEVDadj = VEVD(sgVO2Percent, sgMaskVD) / 60  'L/min
    sgVTVDadj = VTVD(sgVO2Percent, sgMaskVD)  'L
    sgVEadj = sgVEss + sgVERadj + sgVEVDadj  'L/min
    sgVTadj = sgVTss + sgVTRadj + sgVTVDadj  'L
    'determine the vo2 for respirator wear
    sgVO2adj = VO2Adj(sgVEadj)   'L/min
End If
'determine the oxygen deficit
'if no respirator is worn, the O2 deficit is zero
```

```
sgO2Deficit = O2Def(sgVO2adj, sgVO2ss) 'L/min
'determine respiratory rate and respirator period
sgRespRate = RR(sgVEadj, sgVTadj) 'breaths/min
sgRespPeriod = 1 / (sgRespRate / 60) 'sec
'determine inhalation and exhalation times
sgTexp = Te(sgRespPeriod)  'sec
sgTinsp = Ti(sgRespPeriod) 'sec
'determine dimensionless epsilon parameters
'see Johnson (1993) for further explanation
sgEpsilonI = 1 + (sgTexp / sgTinsp)
sgEpsilonE = 1 + (sgTinsp / sgTexp)
'set the maximum muscle pressure that can be developed
'gender effect is included
If sgGender = 0.85 Then
  sgPmax = 6468
Else
  sgPmax = 9996
End If
'***** Set Rohrer coefficients
'***** values are from Johnson (1993)
sgK1aw = 100000 'N s/m^5 - airways
sgK2aw = 10000000 'N s^2/m^8
sgK3aw = 125 'N s/m^2
sgK1lt = 40000# 'lung tissue
sgK1cw = 200000# 'chest wall
If sgGender = 0.85 Then
  myfactor = 0.7 'if female,increase aw coefficients
Else
  myfactor = 1
End If
sgK1Iaw = sgK1aw / myfactor
sgK2Iaw = sgK2aw / myfactor
sgK3Iaw = sgK3aw / myfactor
'exhalation aw values are 10% higher
sgK1Eaw = 1.1 * sgK1aw / myfactor
sgK2Eaw = 1.1 * sgK2aw / myfactor
sgK3Eaw = 1.1 * sgK3aw / myfactor
sgK1I = sgK1Iaw + sgK1lt + sgK1cw
sgK2I = sgK2Iaw
sgK3I = sgK3Iaw
sgK1E = sgK1Eaw + sgK1lt + sgK1cw
sgK2E = sgK2Eaw
sgK3E = sgK3Eaw
'if a respirator is worn K1 and K2 values are affected
'values are for an M17 mask
If inRespirator > 0 Then
  sgK1I = sgK1I + 322700
  sgK1E = sgK1E + 66290
  sgK2I = sgK2I + 56090000
```

```
        sgK2E = sgK2E + 13760000
    End If
    sgCompliance = 0.000001 'm^5/N
    sgInertia = 2600 'N s^2/m^5
    sgVrest = sgFuncResCap
    'sgVC and sgRV are entered by the user
    'determine initial lung volumes
    sgV0i = V0i(sgVitCap, sgResVol, sgVTadj, sgFuncResCap, sgExtWorkRate) 'L
    sgV0e = sgV0i - sgVTadj 'L
'**************************************
    'determine work rate for inhalation and exhalation
    'take waveform into account
    If sgVO2Percent < 40 Then 'less than 40%VO2max
        'use sinusoidal waveform for inhalation
        'use hybrid exponential waveform for exhalation
        sgRespWRinh = SinWR2(sgK1I, sgK2I, sgK3I, sgCompliance, sgVEadj, sgVTadj,
sgTinsp, sgV0i, sgVrest, 0, inRespirator, sgEpsilonI, sgMaskP)
        sgRespWRexh = HybridExp2WR(sgK1E, sgK2E, sgK3E, sgCompliance, sgVEadj,
sgVrest, 1, sgEpsilonE, sgV0e, sgVTadj, sgTexp, sgMaskP, inRespirator)
        'sgRespWRinh = SinWR2(sgK1I, sgK2I, sgK3I, sgCompliance, sgVEadj, sgVTadj,
sgTinsp, sgV0i, sgVRest, 0, inRespirator, sgEpsilonI, sgMaskP)
        'sgRespWRexh = HybridExp2WR(sgK1E, sgK2E, sgK3E, sgCompliance, sgVEadj,
sgVRest, 1, sgEpsilonE, sgV0e, sgVTadj, sgTexp, sgMaskP, inRespirator)
    Else
        'use trapezoidal waveform for inhalation and exhalation
        sgRespWRinh = Trap3WR(sgK1I, sgK2I, sgK3I, sgCompliance, sgVrest, sgMaskP,
inRespirator, sgVTadj, sgTinsp, sgV0i, 0, sgVEadj, sgEpsilonI)
        'sgRespWRinh = TrapWR(sgK1I, sgK2I, sgK3I, sgCompliance, sgVRest, sgMaskP,
inRespirator, sgVTadj, sgTinsp, sgV0i, 0)
        If sgTexp < 0.66 Then
            'flow limited-hybrid exponential waveform used
            sgRespWRexh = FlowLim2WR(sgK1E, sgK2E, sgK3E, sgCompliance, sgInertia,
sgV0e, sgVEadj, sgVTadj, sgEpsilonE, 1, sgFuncResCap, sgTexp, sgResVol, sgMaskP,
inRespirator, sgPmax, sgVitCap)
            'sgRespWRexh = FlowLim2WR(sgK1E, sgK2E, sgK3E, sgCompliance, sgInertia,
sgV0e, sgVEadj, sgVTadj, sgEpsilonE, 1, sgFuncResCap, sgTexp, sgVRest, sgMaskP,
inRespirator, sgPmax, sgVitCap)
        Else
            sgRespWRexh = Trap3WR(sgK1E, sgK2E, sgK3E, sgCompliance, sgVrest,
sgMaskP, inRespirator, sgVTadj, sgTexp, sgV0e, 1, sgVEadj, sgEpsilonE)
            'sgRespWRexh = TrapWR(sgK1E, sgK2E, sgK3E, sgCompliance, sgResVol,
sgMaskP, inRespirator, sgVTadj, sgTexp, sgV0e, 1)
        End If
    End If
    'determine inhalation, exhalation, and total respiratory work
    sgRespWexh = sgRespWRexh * sgTexp
    sgRespWinh = sgRespWRinh * sgTinsp
    sgRespW = sgRespWexh + sgRespWinh
    sgRespWR = sgRespW / sgRespPeriod 'total respiratory work, W
```

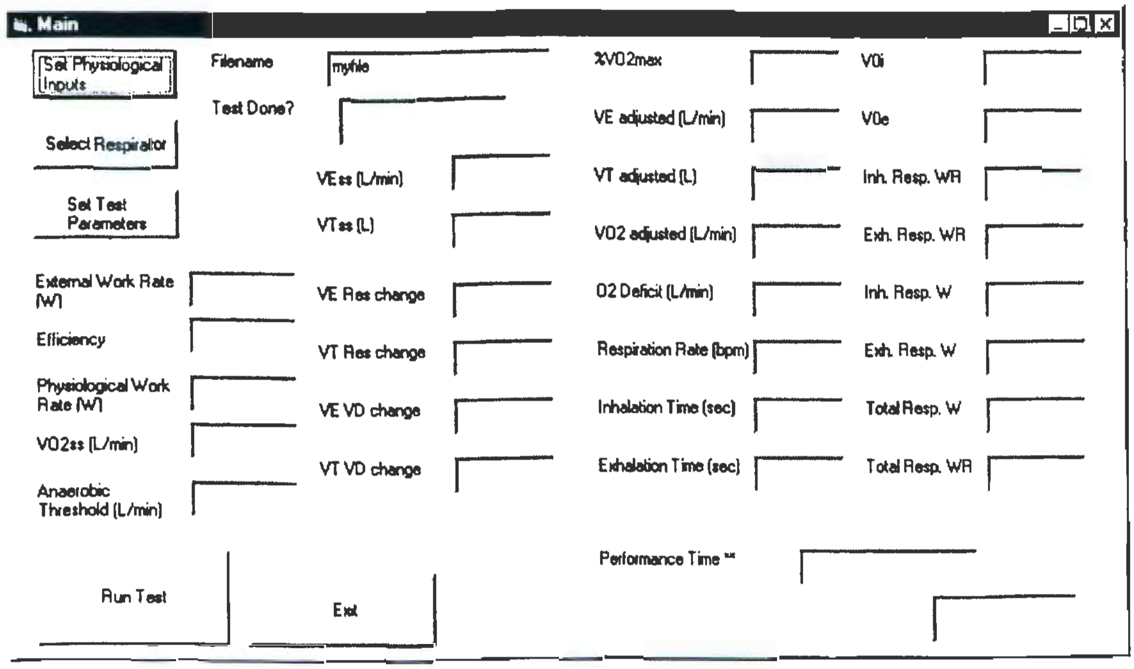
```
    If sgO2Deficit > 0 Then
      'find rough estimate of performance time
      sgPerfTime = sgMaxDeficit / sgO2Deficit 'minutes
    Else
      'respirator not worn
      'because there are no transient effects,
      'O2 deficit is zero and performance time is unlimited
      'by the respiratory system
      sgPerfTime = 999999 'minutes
    End If
'********************************************
'this section was used to validate the WR eqns
'********************************************

'sgVEadj = 110
'sgVTadj = 1.833
'sgTinsp = 0.5
'sgTexp = 0.5
'sgVEadj = 80
'sgVTadj = 1.933
'sgTinsp = 0.7
'sgTexp = 0.75
'sgV0i = sgFuncResCap
'sgV0e = sgFuncResCap
'sgV0e = 3.72
'sgVitCap = 4.8
'sgEpsilonI = 1 + (sgTexp / sgTinsp)
'sgEpsilonE = 1 + (sgTinsp / sgTexp)
'sgRespWRexh = FlowLim2WR(sgK1I, sgK2I, sgK3I, sgCompliance, sgInertia, sgV0e,
sgVEadj, sgVTadj, sgEpsilonE, 1, sgFuncResCap, sgTexp, sgResVol, sgMaskP,
inRespirator, sgPmax, sgVitCap)
'sgRespWRinh = HybridExp2WR(sgK1I, sgK2I, sgK3I, sgCompliance, sgVEadj, sgVrest, 0,
sgEpsilonI, sgV0i, sgVTadj, sgTinsp, sgMaskP, inRespirator)
'sgRespWRexh = HybridExp2WR(sgK1I, sgK2I, sgK3I, sgCompliance, sgVEadj, sgVrest, 1,
sgEpsilonE, sgV0e, sgVTadj, sgTexp, sgMaskP, inRespirator)
'sgRespWRinh = SinWR2(sgK1I, sgK2I, sgK3I, sgCompliance, sgVEadj, sgVTadj, sgTinsp,
sgV0i, sgVrest, 0, inRespirator, sgEpsilonI, sgMaskP)
'sgRespWRexh = SinWR2(sgK1I, sgK2I, sgK3I, sgCompliance, sgVEadj, sgVTadj, sgTexp,
sgV0e, sgVrest, 1, inRespirator, sgEpsilonE, sgMaskP)
'sgRespWRinh = Trap3WR(sgK1I, sgK2I, sgK3I, sgCompliance, sgVrest, sgMaskP,
inRespirator, sgVTadj, sgTinsp, sgV0i, 0, sgVEadj, sgEpsilonI)
'sgRespWRexh = Trap3WR(sgK1I, sgK2I, sgK3I, sgCompliance, sgVrest, sgMaskP,
inRespirator, sgVTadj, sgTexp, sgV0e, 1, sgVEadj, sgEpsilonE)
'frmMain.txtBug1.Text = sgRespWRinh
'frmMain.txtBug2.Text = sgRespWRexh
'********************************************
'***** print parameter values to screen
'********************************************

    frmMain.txtExtWR.Text = sgExtWorkRate
    frmMain.txtEff.Text = sgMuscEff
```

```
   frmMain.txtPhysWR.Text = sgPhysWorkRate
   frmMain.txtVO2ss.Text = sgVO2ss
   frmMain.txtVEss.Text = sgVEss
   frmMain.txtVTss.Text = sgVTss
   frmMain.txtVERes.Text = sgVERadj
   frmMain.txtVTRes.Text = sgVTRadj
   frmMain.txtVEVD.Text = sgVEVDadj
   frmMain.txtVTVD.Text = sgVTVDadj
   frmMain.txtVEadj.Text = sgVEadj
   frmMain.txtVTadj.Text = sgVTadj
   frmMain.txtVO2adj.Text = sgVO2adj
   frmMain.txtO2Def.Text = sgO2Deficit
   frmMain.txtRespRate.Text = sgRespRate
   frmMain.txtTinh.Text = sgTinsp
   frmMain.txtTexh.Text = sgTexp
   frmMain.txtVO2Perc.Text = sgVO2Percent
   frmMain.txtAbsAT.Text = sgAbsAnThresh
   frmMain.txtV0i.Text = sgV0i
   frmMain.txtV0e.Text = sgV0e
   frmMain.txtWRi.Text = sgRespWRinh
   frmMain.txtWRe.Text = sgRespWRexh
   frmMain.txtWi.Text = sgRespWinh
   frmMain.txtWe.Text = sgRespWexh
   frmMain.txtTotalW.Text = sgRespW
   frmMain.txtTotalWR.Text = sgRespWR
   frmMain.txtPerfTime.Text = sgPerfTime

'****************************************************************
'***** write data to file
'****************************************************************
   Print #3, "External Work Rate (W)", sgExtWorkRate
   Print #3, "Gross Efficiency (%)", sgMuscEff * 100
   Print #3, "Physiological Work Rate (W)", sgPhysWorkRate
   Print #3, "Required VO2 (L/min)", sgVO2ss
   Print #3, "VE ss (L/min)", , sgVEss
   Print #3, "VT ss (L)", , sgVTss
   Print #3, "VE Resist. Change (L/min)", sgVERadj
   Print #3, "VT Resist. Change (L)", sgVTRadj
   Print #3, "VE Dead Vol. Change (L/min)", sgVEVDadj
   Print #3, "VT Dead Vol. Change (L)", sgVTVDadj
   Print #3, "Adjusted VE (L/min)", sgVEadj
   Print #3, "Adjusted VT (L)", sgVTadj
   Print #3, "Adjusted VO2 (L/min)", sgVO2adj
   Print #3, "O2 Deficit (L/min)", sgO2Deficit
   Print #3, "Respiration Rate (bpm)", sgRespRate
   Print #3, "T inh (sec)", , sgTinsp
   Print #3, "T exh (sec)", , sgTexp
   Print #3, "%VO2max", , sgVO2Percent
   Print #3, "Resp WR inh (W)", sgRespWRinh
```

```
    Print #3, "Resp WR exh (W)", sgRespWRexh
    Print #3, "Resp W inh (N m)", sgRespWinh
    Print #3, "Resp W exh (N m)", sgRespWexh
    Print #3, "Total Resp Work (N m)", sgRespW
    Print #3, "Resp Work Rate (W)", sgRespWR
    Close #3
    frmMain.txtDoneNow.Text = "ALL DONE!"
End Sub

Private Sub cmdSelectRespirator_Click()
   'shows the form to allow the user to select
   'the respirator that is worn
   frmSelectRespirator.Show
End Sub

Private Sub cmdSetPhysInput_Click()
   'shows the form to change physiological parameters
   frmSetPhysInput.Show
End Sub


Private Sub cmdSetTestInput_Click()
   'shows the form to change the test conditions
   frmSetTestParams.Show
End Sub


Private Sub txtstartfile_Click()
   SendKeys "{Home}+{End}"

End Sub
```

Program Simulation

The program allows the user to investigate changes in pulmonary parameters during exercise with or without a respirator. Once the program is run, the form "Main" is displayed, as shown in Figure 127.



Filename: myfile

Figure 127. The form "Main" that is displayed once the program is run.

From this form, the user has the option to change parameters by clicking on the buttons, "Set Physiological Inputs", "Select Respirator", and "Set Test Parameters". The program is run by clicking on the button "Run Test". Default values are provided for all the parameters so that a simulation may be run without making any changes. The default values also ensure the program will run if the user has not entered a value for one of the parameters.

If the user clicks on the "Set Physiological Inputs" button, the form shown in Figure 128 is displayed.

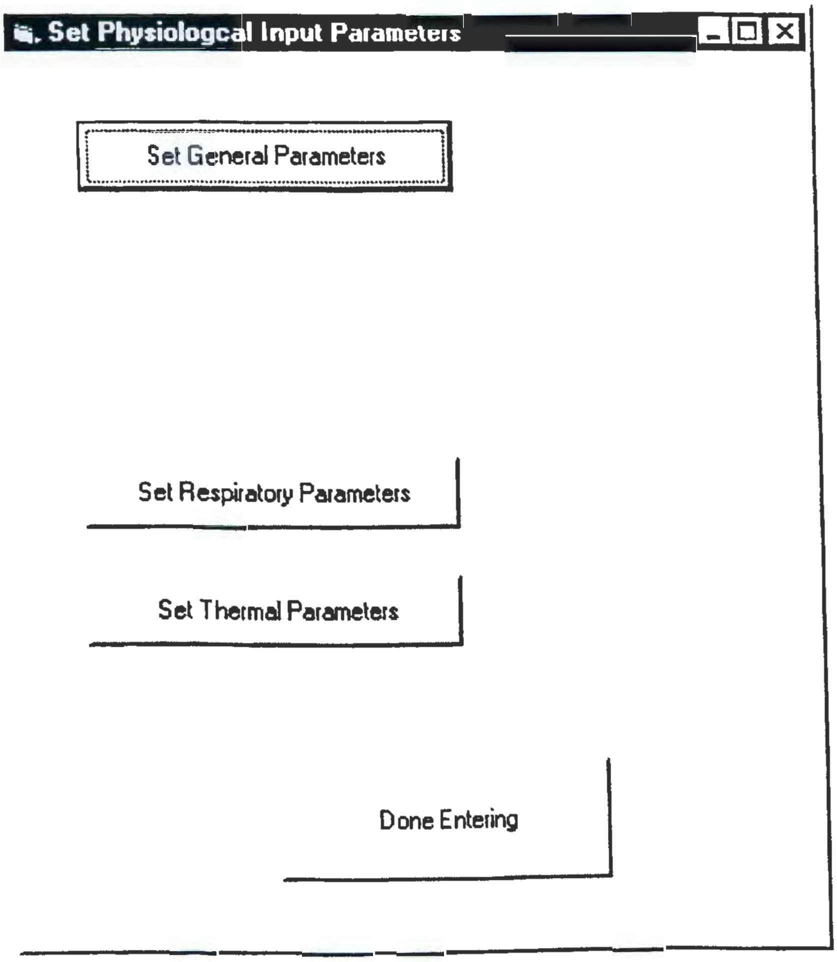
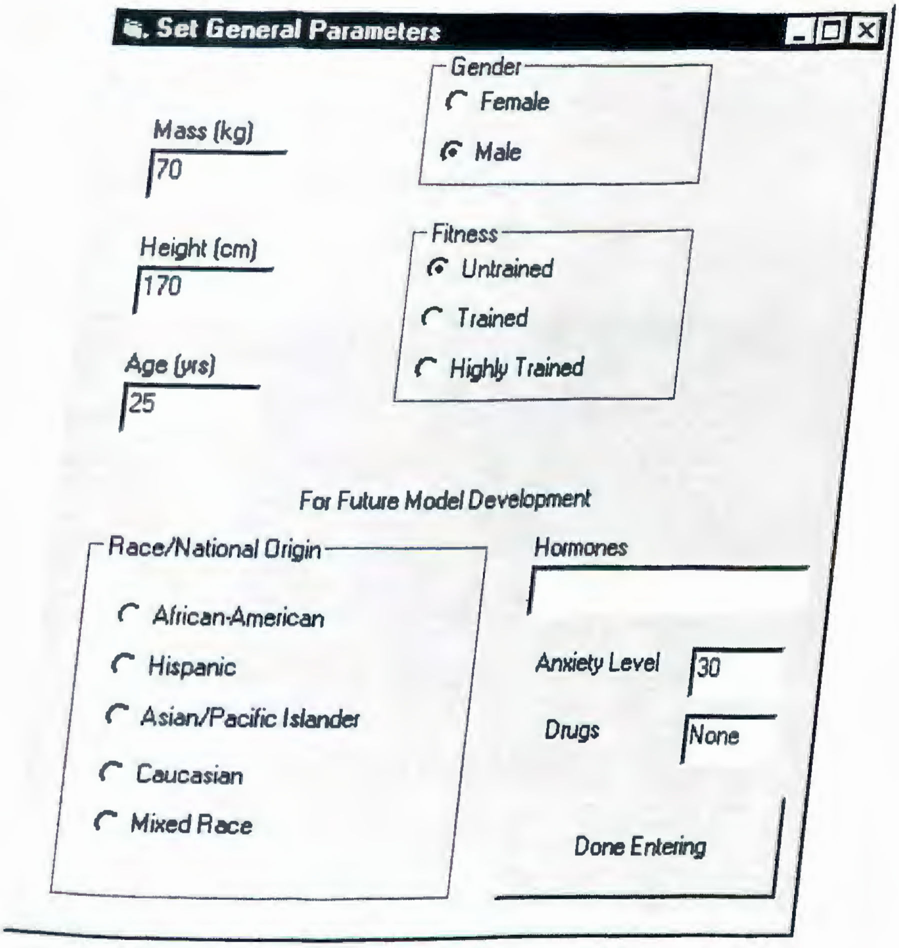


Figure 128. The form for setting the physiological inputs of the model.

From this form, the user can choose to set the general, respiratory, and thermal parameters. When the "Set General Parameters" button is selected the form shown in Figure 129 is displayed.



Set General Parameters

Mass (kg) 70

Height (cm) 170

Age (yrs) 25

Gender
○ Female
● Male

Fitness
● Untrained
○ Trained
○ Highly Trained

For Future Model Development

Race/National Origin
○ African-American
○ Hispanic
○ Asian/Pacific Islander
○ Caucasian
○ Mixed Race

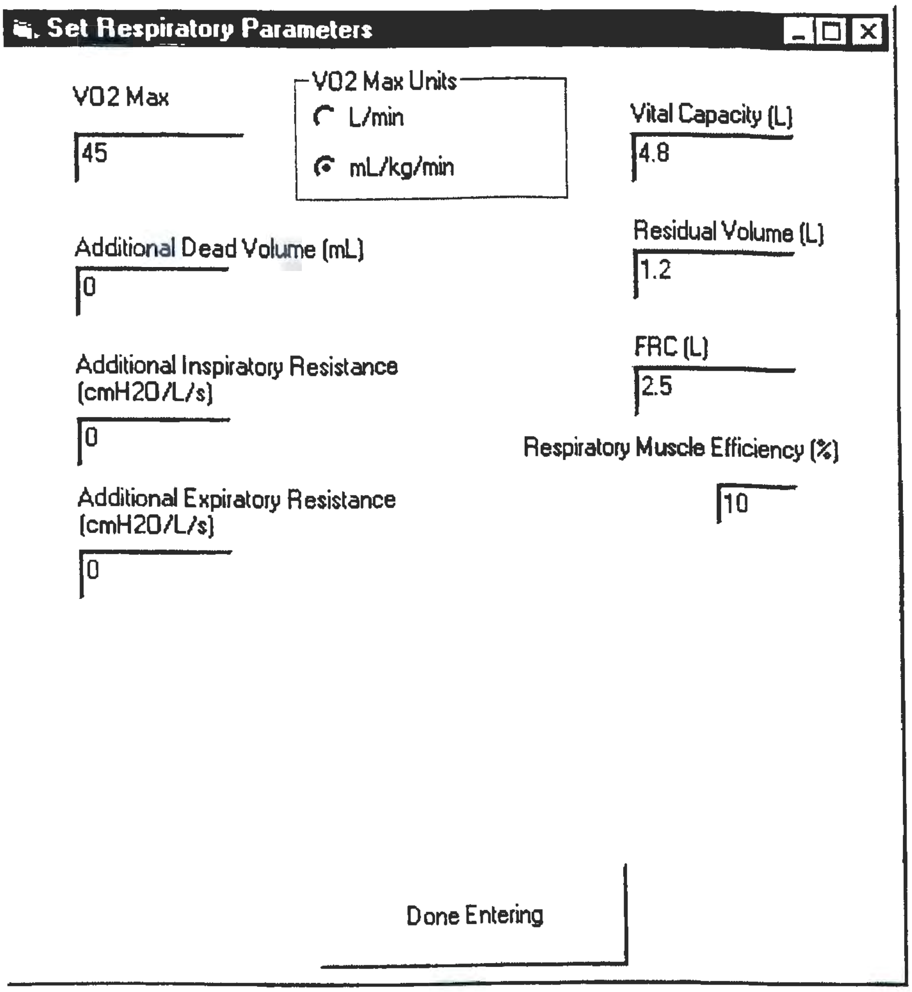
Hormones

Anxiety Level 30

Drugs None

Figure 129. The form for setting the general parameters of the model.

From the form shown in Figure 129, the user can set the mass, height, age, gender, and training status of the subject. Options for setting the race, hormones, anxiety level, and drugs are provided for future development of the model. Each of the text boxes is set up so that if the user clicks in the box the value in the box will be highlighted. To change the value, the user simply types in the new value. Highlighting the value when the box is clicked saves the user from having to delete the existing value. When the user is finished changing the general parameters, the button "Done Entering" is clicked and the user returns to the form for setting the physiological inputs shown in Figure 128. The form shown in Figure 130 is displayed if the user clicks on the button "Set Respiratory Parameters" from the form for setting the physiological inputs.



VO2 Max: 45

VO2 Max Units: ○ L/min ● mL/kg/min

Vital Capacity (L): 4.8

Additional Dead Volume (mL): 0

Residual Volume (L): 1.2

Additional Inspiratory Resistance (cmH20/L/s): 0

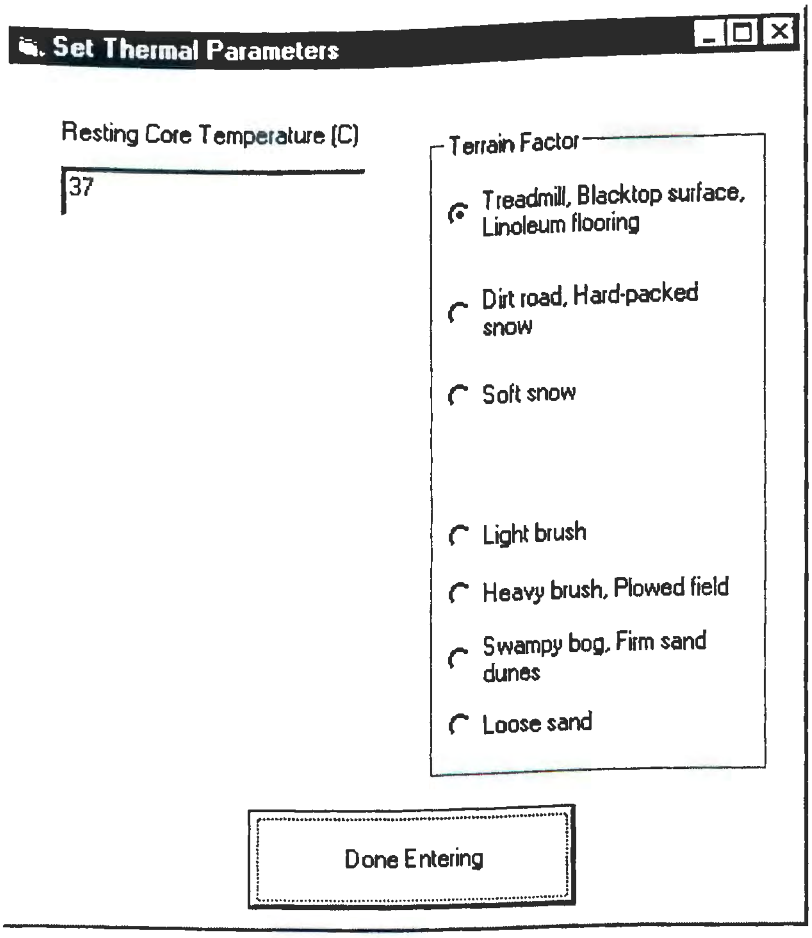
FRC (L): 2.5

Respiratory Muscle Efficiency (%): 10

Additional Expiratory Resistance (cmH20/L/s): 0

Figure 130. The form for changing the respiratory parameters in the model.

From this form, the VO2max may be entered in either relative (mL/kg/min) or absolute (L/min) terms. Additional respiratory resistance and dead volume may be entered. The vital capacity, residual volume, functional residual capacity, and respiratory muscle efficiency may also be changed from this form. When the user is done changing the respiratory parameters, the button "Done Entering" should be clicked. The user is returned to the form shown in Figure 128 for entering the physiological parameters. When the button "Set Thermal Parameters" is clicked, the form given in Figure 131 is shown.



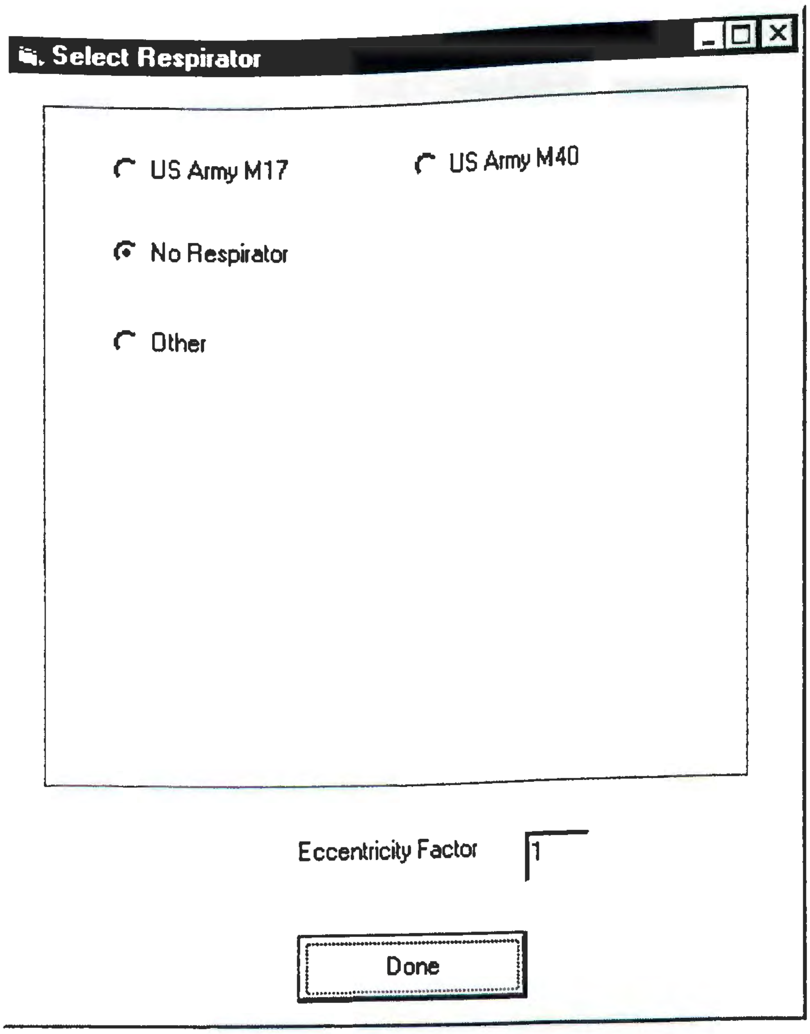
Resting Core Temperature (C)
37

Terrain Factor
- ● Treadmill, Blacktop surface, Linoleum flooring
- ○ Dirt road, Hard-packed snow
- ○ Soft snow
- ○ Light brush
- ○ Heavy brush, Plowed field
- ○ Swampy bog, Firm sand dunes
- ○ Loose sand

Figure 131. The form for setting the thermal parameters in the model.

From this form the user may enter the resting core temperature of the subject and the type of terrain on which the subject will be walking or running. When the user is done entering these parameters, the button "Done Entering" is clicked and the user returns to the form shown in Figure 128 for setting the physiological parameters. Once the user has finished changing the general, respiratory, and thermal parameters, the button "Done Entering" is clicked and the user returns to the main form shown in Figure 127.

If the user selects the button "Select Respirator", the form given in Figure 132 is shown.

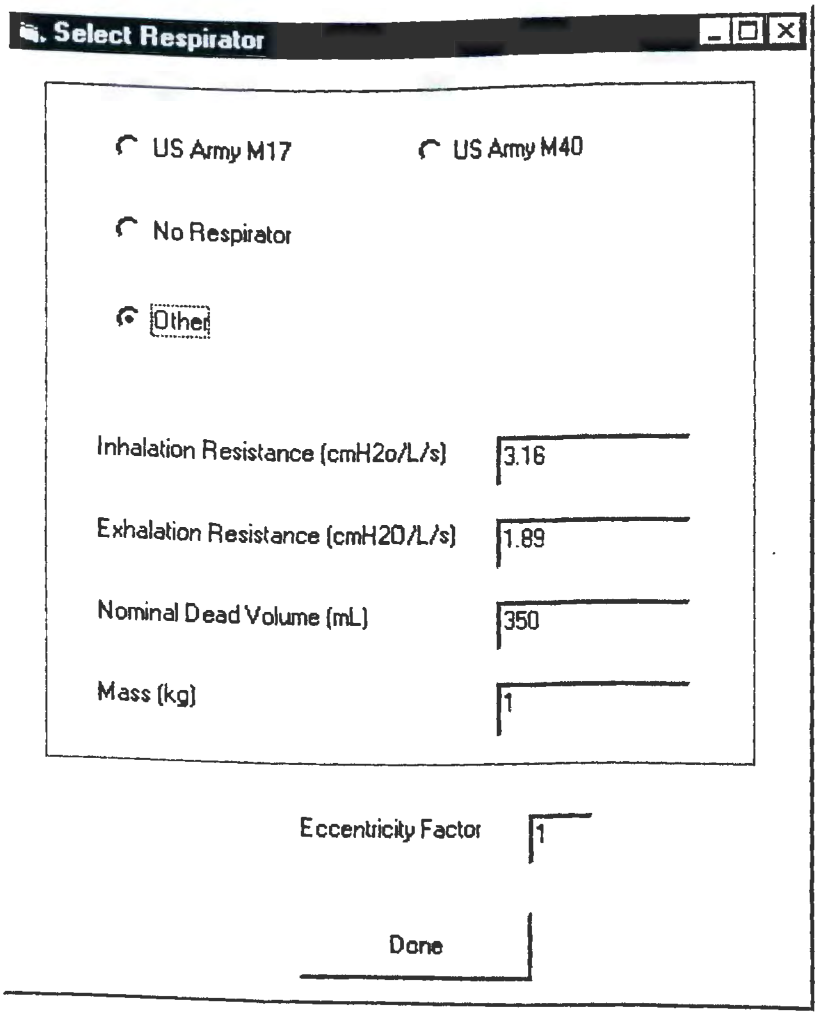


○ US Army M17
○ US Army M40
● No Respirator
○ Other

Eccentricity Factor 1

Figure 132. The form for selecting the respirator worn by the subject in the model.

From this form, the user may select no respirator, the U. S. Army M17, the U.S. Army M40, or another respirator. The parameter "Eccentricity Factor" takes into account the fact that the mass of the respirator is not distributed evenly over the head and is provided for future development of the model. If the option "Other" is selected, additional text boxes are displayed for entering the inhalation and exhalation resistance, dead volume, and mass of the respirator as shown in Figure 133.



○ US Army M17 ○ US Army M40

○ No Respirator

● Other

Inhalation Resistance (cmH2o/L/s) 3.16

Exhalation Resistance (cmH20/L/s) 1.89

Nominal Dead Volume (mL) 350

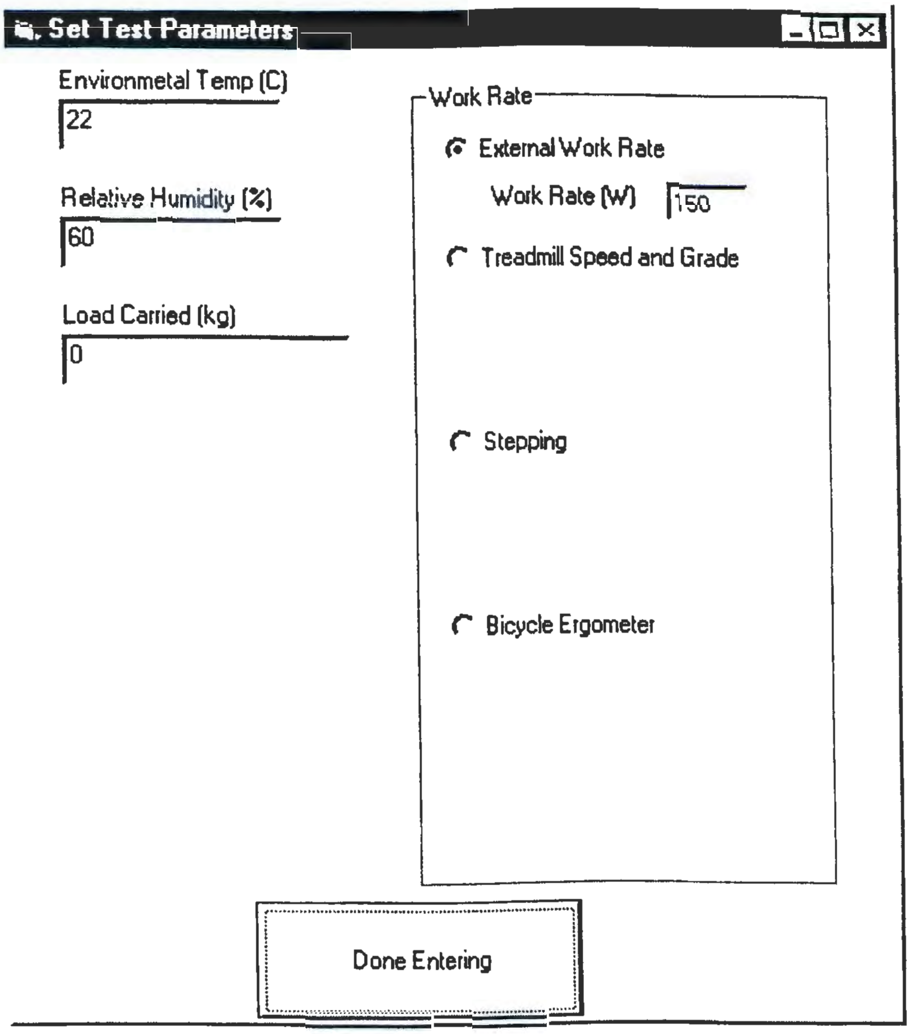
Mass (kg) 1

Eccentricity Factor 1

Figure 133. Text boxes displayed when "Other" respirator is selected.

When the user has finished selecting the respirator, the "Done" button is clicked and the user is returned to the main form shown in Figure 127.

Clicking on the button "Set Test Parameters" will display the form shown in Figure 134.



Environmetal Temp (C) 22

Relative Humidity (%) 60

Load Carried (kg) 0

● External Work Rate

Work Rate (W) 150

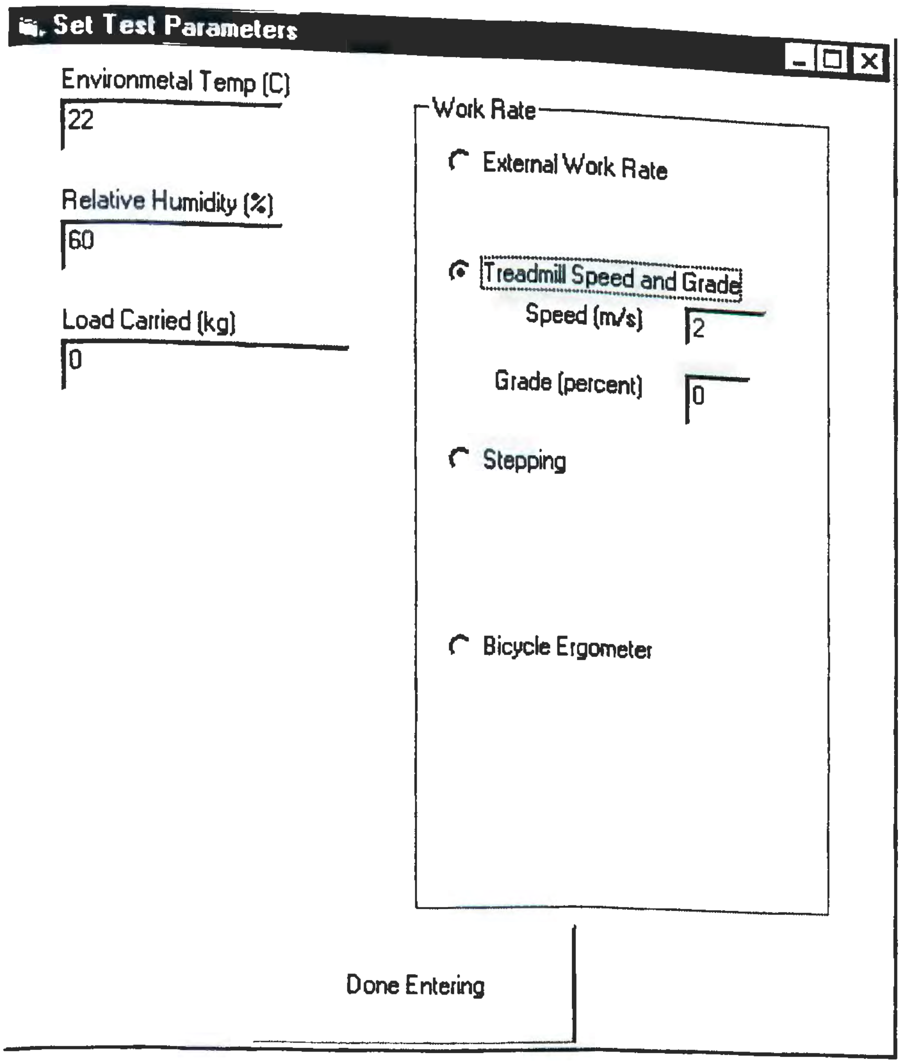
○ Treadmill Speed and Grade

○ Stepping

○ Bicycle Ergometer

Figure 134. The form for setting the test conditions in the model.

The environmental temperature and humidity, the load carried by the subject, and the work rate may be changed on this form. The user may either specify the external work rate or may select treadmill, stepping, or ergometry exercise. If treadmill exercise is chosen, additional text boxes appear on the form for setting the treadmill speed and grade as shown in Figure 135.



Environmetal Temp (C): 22

Relative Humidity (%): 60

Load Carried (kg): 0

○ External Work Rate

● Treadmill Speed and Grade

Speed (m/s): 2

Grade (percent): 0

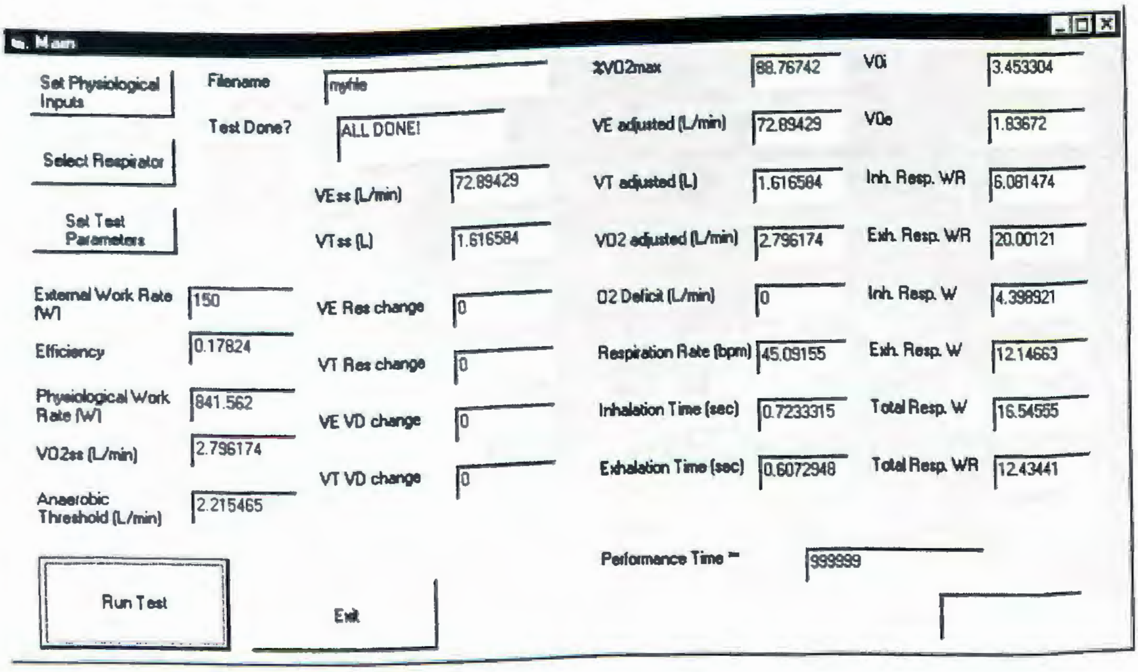
○ Stepping

○ Bicycle Ergometer

Figure 135. The form for setting the test parameters when treadmill activity is selected.

When the treadmill activity is selected, the text box for entering the external work rate disappears. Similarly, if external work rate is again selected or if stepping or bicycle ergometry are selected the speed and grade text boxes disappear. When the user is finished setting the test parameters, the button "Done Entering" is clicked and the user is returned to the main form.

When the user is finished changing parameters, a simulation may be run by selecting the button "Run Test". If the model is run without changing any of the parameters, the form "Main" will appear as in Figure 136.



Filename: myfile
Test Done?: ALL DONE!
External Work Rate (W): 150
Efficiency: 0.17824
Physiological Work Rate (W): 841.562
VO2ss (L/min): 2.796174
Anaerobic Threshold (L/min): 2.215465
VEss (L/min): 72.89429
VTss (L): 1.616584
VE Res change: 0
VT Res change: 0
VE VD change: 0
VT VD change: 0
%VO2max: 88.76742
VE adjusted (L/min): 72.89429
VT adjusted (L): 1.616584
VO2 adjusted (L/min): 2.796174
O2 Deficit (L/min): 0
Respiration Rate (bpm): 45.09155
Inhalation Time (sec): 0.7233315
Exhalation Time (sec): 0.6072948
VOi: 3.453304
VOe: 1.83672
Inh. Resp. WR: 6.081474
Exh. Resp. WR: 20.00121
Inh. Resp. W: 4.398921
Exh. Resp. W: 12.14663
Total Resp. W: 16.54555
Total Resp. WR: 12.43441
Performance Time =: 999999

Figure 136. The main form after a simulation has been run with the default parameters.

Values appear in the text boxes for each of the respiratory parameters. The performance time for the no respirator condition defaults to 999,999 minutes. Because transient effects were not included, there is no oxygen deficit for the no respirator condition. This means that the performance time would theoretically be infinite. Two output files are generated each time the model is run. The filename may be changed by the user on the form “Main”. One file contains the initial values of all the parameters while the other contains all the results. The two output files for the current simulation are shown in Tables 70 and 71.

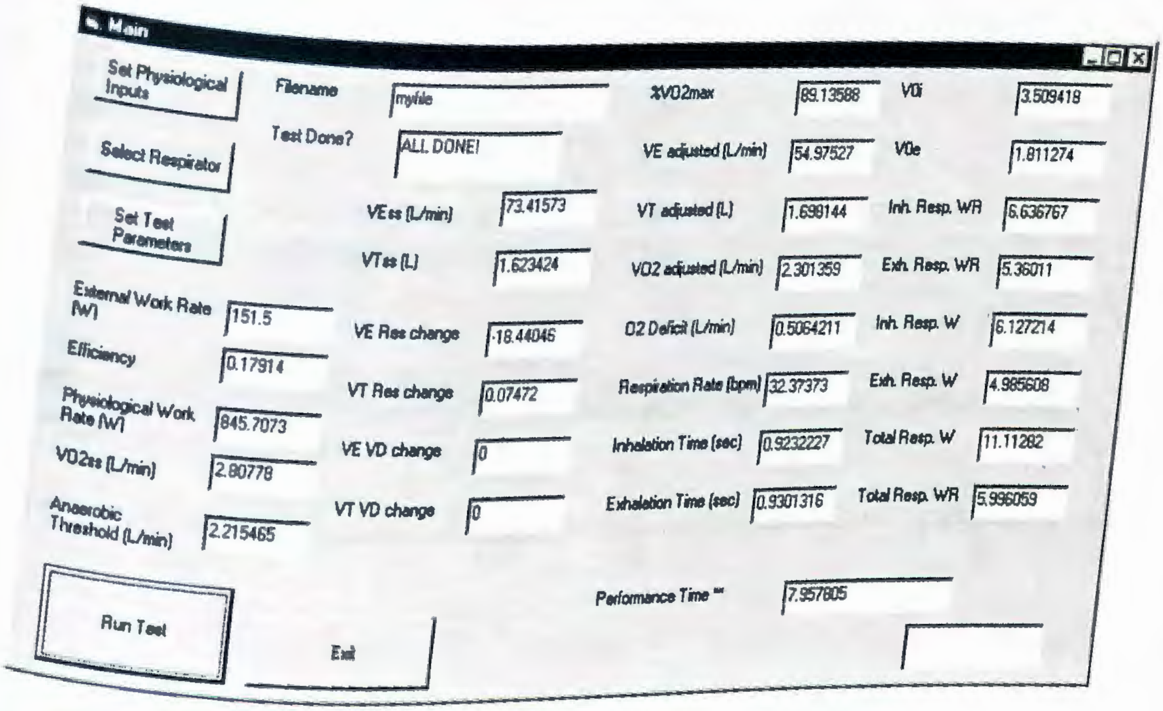
Table 71. The first output file from the model showing the initial parameter values.

```
Start Conditions File
Trial conducted: 6/13/01    6:21:51 PM
**************************************************************
Subject Characteristics
----------------------
Mass (kg)        70
Height (m)       1.7
Age (yr)        25
Gender          Male
Fitness         Untrained
**************************************************************
Thermal Inputs
----------------------
Core Temp                        37
Terrain Factor                   1
**************************************************************
Respiratory Inputs
------------------
VO2 max (L/min)                                      3.15
VO2max (mL/kg/min)                                   45
Vital Capacity (L)                                   4.8
Residual Volume (L)                                  1.2
Functional Residual Capacity (L)                     2.5
Resp. Musc. Eff. (%)                                 10
Additional Resp. Res. Inh. (cmH20/L/s)               0
Additional Resp. Res. Exhh. (cmH20/L/s)              0
Additional Resp. Dead Vol. (L)                       0
**************************************************************
Respirator Selected
-------------------
None
**************************************************************
Test Inputs
-----------
Environ. Temp.(C)                22
Rel. Humidity (%)                60
Load Carried (kg)                0
External Work Rate (W)           150
```

Table 72. The second file generated by the model showing the results of the simulation.

```
Respiratory Data #1
Trial conducted: 6/13/01    6:21:51 PM
*****************************************************************
External Work Rate (W)      150
Gross Efficiency (%)        17.824
Physiological Work Rate (W) 841.562
Required VO2 (L/min)        2.796174
VE ss (L/min)               72.89429
VT ss (L)                   1.616584
VE Resist. Change (L/min)   0
VT Resist. Change (L)       0
VE Dead Vol. Change (L/min) 0
VT Dead Vol. Change (L)     0
Adjusted VE (L/min)         72.89429
Adjusted VT (L)             1.616584
Adjusted VO2 (L/min)        2.796174
O2 Deficit (L/min)          0
Respiration Rate (bpm)      45.09155
T inh (sec)                 0.7233315
T exh (sec)                 0.6072948
%VO2max                     88.76742
Resp WR inh (W)             6.081474
Resp WR exh (W)             20.00121
Resp W inh (N m)            4.398921
Resp W exh (N m)            12.14663
Total Resp Work (N m)       16.54555
Resp Work Rate (W)          12.43441
```

If a simulation is run with the default values except that the U. S. Army M40 is selected instead of the no respirator condition, the form will appear as in Figure 137.



Filename myfile
Test Done? ALL DONE!
External Work Rate (W) 151.5
Efficiency 0.17914
Physiological Work Rate (W) 845.7073
VO2ss (L/min) 2.80778
Anaerobic Threshold (L/min) 2.215465
VEss (L/min) 73.41573
VTss (L) 1.623424
VE Res change -18.44046
VT Res change 0.07472
VE VD change 0
VT VD change 0
%VO2max 89.13588
VE adjusted (L/min) 54.97527
VT adjusted (L) 1.698144
VO2 adjusted (L/min) 2.301359
O2 Deficit (L/min) 0.5064211
Respiration Rate (bpm) 32.37373
Inhalation Time (sec) 0.9232227
Exhalation Time (sec) 0.9301316
VOi 3.509418
VOe 1.811274
Inh. Resp. WR 6.636767
Exh. Resp. WR 5.36011
Inh. Resp. W 6.127214
Exh. Resp. W 4.985608
Total Resp. W 11.11282
Total Resp. WR 5.996059
Performance Time ** 7.957805

Figure 137. The main form after a simulation is run with the default values and the U. S. Army M40 respirator.

The effects of the respirator can be seen by examining the minute ventilation, tidal volume, and oxygen consumption. The minute ventilation and oxygen consumption are lower with the mask and the tidal volume is higher. These results were expected.

Additional simulations can be run after parameter values have been changed. When the user is finished, the program can be stopped by clicking on the “Exit” button.

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