OXYGEN CONSUMPTION AND CARBON DIOXIDE ELIMINATION DURING NORMAL AND HYPERVENTILATED BREATHING AT PROGRESSIVE WORK RATES

by:

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ABSTRACT

This study was undertaken to determine and compare the rates of oxygen consumption and carbon dioxide elimination during normal and hyperventilated breathing at progressive work rates.

Three subjects stepped at 18, 24, 30, 36 and 40 steps per minute on an eighteen inch bench for a duration of ten minutes or until exhaustion.

All exercises were performed inside a 6,900 liter closed circuit respirometer. The volume of each subject obtained from hydrostatic weighings was subtracted from the chamber volume as was the volume of the bench. Net volume was corrected to STPD. The respirometer was equipped with Beckman oxygen and carbon dioxide analyzers, an internal cooling system as well as wet and dry thermocouples on three sides.

Oxygen and carbon dioxide concentrations were continuously analyzed and automatically recorded against time. A resting metabolic rate was established prior to each work task. Completion of the exercise was followed by a fifteen minute recovery period. Curves of cumulative oxygen consumption (VO_2) and carbon dioxide elimination (VCO_2) were plotted against time. By determining the gradients of these curves at different points it was possible to plot the corresponding velocity curves ($\dot{V}O_2$, $\dot{V}CO_2$). The acceleration curves ($\ddot{V}O_2$, $\ddot{V}CO_2$) were derived from the velocity curves. An IBM computer program was used to determine the velocity and acceleration values.

When compared to normal breathing, hyperventilating at the higher work loads increases the VO_2 and VCO_2 during the early phase of exercise. This is generally followed by decreased VO_2 during the recovery period. There are well defined differences in the derivative curves between normal and hyperventilated breathing. Implications for athletic performance are indicated. Derivative curves of oxygen consumption and carbon dioxide elimination appear to be highly individual. Their use as a fitness criterion is indicated.

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CHAPTER I

STATEMENT OF THE PROBLEM

This study was undertaken to investigate, by indirect calorimetry, oxygen consumption and carbon dioxide elimination during normal and hyperventilated breathing at progressive work rates. The problem was to determine whether it is possible to alter the course of gaseous interchange and transport during exercise by the voluntary control of respiration. Morehouse and Miller (1) state, "Endurance for exhaustive work depends mainly on the ability of the body to supply and use oxygen, to endure and dispose of the rapidly mounting concentrations of lactic acid and carbon dioxide and finally on the functional capacity of the heart, lungs, kidneys and the organs that sustain activity." The oxygen debt after submaximal work is directly related to the lag in the oxygen uptake at the beginning of work before a steady state is reached when the oxygen intake equals the requirement (2). Otis (3) states that the stress of muscular exercise creates problems of oxygen supply to the tissues of the body. The body responds by bringing into play homeostatic mechanisms which augment this supply to meet the increased demand, thereby minimizing the fall in oxygen supply to the tissues. Numerous investigators (4, 5, 6, 7, 8, 9) have reported increases in ventilation occurring simultaneously with the onset of exercise thus showing the importance of involuntary hyperventilation during exercise. The problem remains however whether the spontaneous increase in ventilation in response to exercise is adequate in terms of oxygen supply to exercising tissue or whether voluntary hyperventilation can increase the velocity of oxygen uptake ($\dot{V}O_2$) in the early phases of exercise and decrease the initial lag in oxygen consumption prior to attaining a steady state. Krustev (10) asserts that oxygen uptake as well as carbon dioxide separation can be increased by correct breathing.

The closed circuit chamber eliminates the resistances of air passageways and therefore provides an ideal environment for experiments on voluntary hyperventilation during exercise.

Delimitations

1. Three subjects voluntarily participated in the experiment.

2. Hyperventilation was dependent on subject control.

3. Respiratory frequencies and tidal volumes were not recorded.

Limitations

1. The closed circuit chamber although used extensively for research purposes on metabolic activities of animals at rest had not been previously utilized for studies on the exercise physiology of humans.

2. A limited work task was used i.e. a stepping exercise involving no arm movements.

Assumptions

1. Any differences obtained in VO_2 and VCO_2 are due to the specific breathing technique adapted during the exercise task.

Definitions

1. For purposes of this study hyperventilation was defined as a controlled breathing technique with emphasis on deep inhalations and forceful exhalations.

REFERENCES

1. Morehouse, L. E., Miller, A. T., Physiology of Exercise, 4th ed., St. Louis, C. V. Mosby, 1963, p. 237.

2. Taylor, H. L., Science and Medicine of Exercise and Sports, New York, Harper and Brothers, 1960, p. 128.

3. Otis, A. B., "Physiology of Respiration in Relation to Environment and to Muscular Exercise", The Journal of Sports Medicine and Physical Fitness, vol. 2 (June 1962), pp. 83-85.

4. Torelli, G., Brandi, G., "The Hyperventilation in the First 15 Seconds of Muscular Work", The Journal of Sports Medicine and Physical Fitness, vol. 4 (March 1964), pp. 25-27.

5. Otis, op. cit., p. 83.

6. Torelli, G., Brandi, G., "The Components of Nervous Regulation of the Ventilation", The Journal of Sports Medicine and Physical Fitness, vol. 4 (June 1964), pp. 75-78.

7. Hickam, J. B., Pryor, W. W., Page, E. B., Atwell, R. J., "Respiratory Regulation During Exercise in Unconditioned Subjects", Journal of Clinical Investigation, vol. 30 (May 1951), pp. 503-516.

8. Asmussen, E., Nielsen, M., "Studies on the Regulation of Respiration in Heavy Work", Acta Physiologica Scandinavica, vol. 12 (1946), pp. 171-187.

9. Krumholz, R. A., Ross, J. C., "Secondary Ventilatory Response to Exercise Modifications by Agents Which Alter CBF", Journal of Applied Physiology, vol. 20 (March 1965), pp. 257-262.

10. Krustev, K., "Oxygen and Sporting Achievement", Bulletin D'Information, Comite' Olympique Bulgare, vol. 5 (May 1963), pp. 26-28.

CHAPTER II

JUSTIFICATION OF THE PROBLEM

According to Ramanathan (1), the primary response to an increased rate of energy expenditure is an increased oxygen uptake by the lungs. However, respiratory changes during exercise have not been extensively investigated and Krumholz (2) states, "The mechanisms for the ventilatory response to exercise are not well understood."

Krotev (3) has shown that breathing is a vital function, strongly activated in the course of sporting activities. Maccagno (4) states:

> For some reason athletes with exceptional physical means cannot achieve particular goals. Frequently a reason is a defective respiratory technique which prevents attainment of perfect harmony in various systems used during effort.

Upon investigation, Krotev (5) discovered frequent conditions in labouring activities and sports in which one or other of the respiratory phases, inhalation and exhalation, was found to be hindered or facilitated. This, he felt, showed good reason to study the problem of voluntary regulating the breathing cycle and methods specifically designed to improve it. The oxygen demands of sedentary and common light - labour occupations are usually met at the involuntary reflex level, whereas in sports requiring a great output of muscular effort or speed, or both, much attention is given to breath control (6). Miles (7) suggests that data on the specific problems of respiratory training exercises would seem to be of research interest.

Christie (8) points out the feasability of controlled experiments on respiratory movements. "Respiration is one of the many rhythmic processes but it is almost unique in that its rhythm can at any time be altered by voluntary control" (9). Otis (10) reports that most of the best data regarding respiratory phenomena in exercise have been obtained with subjects in a steady state. ". . . more information about events occurring during the transient period at the beginning of exercise before the steady state is attained is needed." (11). Continuous recording of the gaseous concentrations of the respiratory gases as obtained in the closed circuit chamber might enable observations during this transient period.

REFERENCES

1. Ramanathan, N. L., "Reliability of Estimation of Metabolic Levels from Respiratory Frequency", Journal of Applied Physiology, vol. 19 (May 1964), pp. 497-502.

2. Krumholz, R. A., Ross, J. C., "Secondary Ventilatory Response to Exercise: Modifications by Agents Which Alter CBF", Journal of Applied Physiology, vol. 20 (March 1965), p. 257.

3. Krotev, L., "New Concept of Breathing", Bulletin d'Information, Comite' Olympique Bulgare, vol. 9 (Dec. 1963), pp. 26-28.

4. Maccagno, A. L., "New Methods for Evaluating Respiratory Functioning in Athletes", The Journal of Sports Medicine and Physical Fitness, vol. 4 (Dec. 1964), p. 204.

5. Krotev, op. cit., p. 28.

6. Miles, W. R., "Oxygen Consumption During Three Yoga-type Breathing Patterns", Journal of Applied Physiology, vol. 19 (Jan. 1964), p. 75.

7. Ibid., p. 75.

8. Christie, R. V., "Dypnoea in Relation to the Visco-Elastic Properties of the Lung", Proceedings of the Royal Society of Medicine, vol. 46 (May 1953), pp. 381-386.

9. Ibid., p. 381.

10. Otis, A. B., "Physiology of Respiration in Relation to Environment and to Muscular Exercise", The Journal of Sports Medicine and Physical Fitness, vol. 2 (June 1962), pp. 83-85.

11. Ibid., p. 84.

CHAPTER III

REVIEW OF THE LITERATURE

The Ventilatory Response to Exercise

The stress of muscular exercise creates problems of adequate oxygen supply to the tissues of the body. The body responds by bringing into play homeostatic mechanisms one of which is increased pulmonary ventilation (1, 2, 3, 4). Krumholz (5) asserts that the mechanisms for the ventilatory response to exercise are not well understood. Chemical factors cannot be responsible for the initial immediate increase in ventilation and hence nervous factors are implied (6,7,8,9). Krogh et. al. (10) found that values taken in the first few seconds of exercise indicate that the increase in oxygen absorption is not abrupt but takes place gradually and there would seem to be a latent period of a few seconds. Hickam et. al. (11) and Krumholz (12) have shown that the immediate increase in ventilation is maintained approximately for one minute. After this a sharp increase in ventilation occurred, referred to as the secondary ventilatory response to exercise. This interval was found to decrease as the level of exercise increased. Hickam (13) hypothesized that the difference may reflect a lag between arterial blood changes and ventilatory response. Krogh (14) found large individual differences between ventilatory response to work load depending on training. Individuals trained to sudden exertions show large immediate increases in ventilation with the onset of heavy work.

Despite the fact that considerable research has dealt with the ventilatory response to exercise and its regulation, little investigation has been concerned with the adequacy of this response.

The Work of Breathing

The work of breathing, estimated from measurements of oxygen consumption of the muscles of breathing is defined as the oxygen cost of breathing (15, 16). Work is done in overcoming the elastic recoil of the lungs and chest as well as the airway resistances and tissue viscosity involved (17, 18). Christie (19) estimates that sixty percent of the work is involved in overcoming elastic resistances and forty percent the viscous nonelastic resistances. Christie (20) and Mead (21) report large muscle forces needed to overcome the elastic recoil of lungs and thorax when breathing at low frequencies and large tidal volumes. Similarly with rapid shallow breathing increased flow requires increased muscle force and rate of work. Bartlett (22) concludes that the optimal breathing frequency for any pulmonary ventilation is determined by the elastic work, which decreases with increased breathing rates and the nonelastic work, which decreases with decreased breathing rate. It is clear that in exercise as well as at rest the normal individual selects the respiratory rate and depth which is most economical in terms of respiratory work (23, 24). It has however been pointed out that these rates are not optimal for sustaining activity. Krotev's (25) investigation has shown that expiration is a true bottleneck of gaseous exchange. For this reason its duration, intensity and volume are only too relevant to the efficient functioning of the organism and it is unacceptable to assume that it is realized simply by the mechanical elastic forces of lungs and chest. These are anatomically and functionally unfit for rapid adaptive change. Krustev (26) and Miles (27) conclude that oxygen intake can be considerably increased by regulated respiratory movements. Maccagno (28) has shown that defective respiratory techniques will prevent athletes with exceptional physical means from achieving particular goals.

The Oxygen Cost of Voluntary Hyperventilation

Differences between oxygen uptake during normal and hyperventilated breathing are considered to be the oxygen cost of voluntary hyperventilation (29). Such values have been generally obtained with a subject in sitting position and at rest (30, 31). The oxygen cost of voluntary hyperventilation in this manner has been found to be very high. McKerrow _et_. _al_. (32) report the cost of maximum voluntary hyperventilation as high as two liters oxygen per minute. Murray (33) found the cost of voluntary hyperventilation ranging from 3.1 to 3.3 ml oxygen per liter of ventilation increase. The relationship between the energy requirement for ventilation and ventilation itself it not linear but increases exponentially and thus theoretically the ventilation rate will have a limiting value since further increases in ventilation will make no more oxygen available for this task except by lowering PO_2 in the alveoli (34, 35). McKerrow (36) explains these observations by stating that the mechanical work required per unit ventilation is not constant but increases with increasing ventilation. Furthermore, it is also related to muscular efforts not directly associated with respiratory movements.

One cannot assume that such estimates are valid for the oxygen cost of hyperventilation during exercise. Christie (37) discovered that normal individuals required less respiratory work to double ventilation during exercise than at rest. He concluded that in health lungs become more distensible during exercise. Milic-Emili *et. al.* (39) report small energy expenditures of the respiratory muscles during exercise in both trained and untrained subjects. Liljestrand (38) believed voluntary hyperventilation needed more oxygen because it involved inefficient muscular action. The cost of voluntary hyperventilation was found to be much higher than that induced by increasing carbon dioxide concentration of the alveoli. Margaria *et. al.* (40) report the work of breathing during exercise to be relatively small: no more than three percent of the total energy consumed by the subject.

REFERENCES

1. Morehouse, L. E., Miller, A. T., Physiology of Exercise, 4th ed., Saint Louis, C. V. Mosby, 1963, p. 146.

2. Ramanathan, N. L., "Reliability of Estimation of Metabolic Levels from Respiratory Frequency", Journal of Applied Physiology, vol. 19 (May 1964), pp. 497-502.

3. Otis, A. B., "Physiology of Respiration in Relation to Environment and to Muscular Exercise", Journal of Sports Medicine and Physical Fitness, vol. 2 (June 1962), pp. 83-85.

4. Torelli, G., Brandi, G., "The Components of Nervous Regulation of the Ventilation", The Journal of Sports Medicine and Physical Fitness, vol. 4 (June 1964), pp. 75-78.

5. Krumholz, R. A., Ross, G. C., "Secondary Ventilatory Response to Exercise: Modifications by Agents Which Alter CBF", Journal of Applied Physiology, vol. 20 (March 1965), pp. 257-262.

6. Torelli, Op. cit., p. 75.

7. Hickam, J. B., Pryor, W. W., Page, E. B., Atwell, R. J., "Respiratory Regulation During Exercise in Unconditioned Subjects", Journal of Clinical Investigation, vol. 30 (May 1951), pp. 503-516.

8. Torelli, G., Brandi, G., "The Hyperventilation in the First 15 seconds of Muscular Work", The Journal of Sports Medicine and Physical Fitness, vol. 4 (March 1964), pp. 25-27.

9. Storey, W. F., Butler, J., "Evidence That the PCO_2 of Mixed Venous Blood is Not a Regulator of Ventilation During Exercise", Journal of Applied Physiology, vol. 18 (March 1963), pp. 345-348.

10. Krogh, A., Lindhard, J., "The Regulation of Respiration and Circulation During The Initial Stages of Muscular Work", Journal of Physiology, vol. 47 (October 1913), pp. 112-136.

11. Hickam, op. cit., pp. 507-508.

12. Krumholz, op. cit., p. 257

13. Hickam, op. cit., p. 508.

14. Krogh, <u>op, cit.</u>, pp. 113-114.

15. Otis, A. B., "The Work of Breathing", <u>Physiological Reviews</u>, vol. 34 (July 1954), pp. 449-458.

16. Riley, R. L., "The Work of Breathing And Its Relation to Respiratory Acidosis, <u>Annals of Internal Medicine</u>, vol. 41 (1954), pp. 172-176.

17. Margaria, R., Milic-Emeli, G., Petit, J. M., Cavagna, G., "Mechanical Work of Breathing during Muscular Exercise", <u>Journal of Applied Physiology</u>, vol. 15 (May 1960), pp. 354-358.

18. Bartlett, R. G., Bruback, H. F., Specht, H., "Oxygen Cost of Breathing", <u>Journal of Applied Physiology</u>, vol. 12 (1958), pp. 413-424.

19. Christie, R. V., "Dypnoea in Relation to the Visco-Elastic Properties of the Lung", <u>Proceedings of the Royal Society of Medicine</u>, vol. 46 (May 1953), pp. 381-386.

20. <u>Loc. cit.</u>

21. Mead, J., "Control of Respiratory Frequency", <u>Journal of Applied Physiology</u>, vol. 15 (May 1960), pp. 325-336.

22. Bartlett, <u>op. cit.</u>, p. 422.

23. Christie, <u>op. cit.</u>, p. 283.

24. Bartlett, <u>op. cit.</u>, p. 423.

25. Krotev., L., "New Concept of Breathing", <u>Comite' Olympique Bulgare, Bulletin D'Information</u>, vol. 9 (1963), pp. 26-28.

26. Krustev, K., "Oxygen and Sporting Achievement", <u>Comite' Olympique Bulgare, Bulletin D'Information</u>, (1963), vol. 5, pp. 26-28.

27. Miles, W. K., "Oxygen Consumption During Three Yoga-type Breathing Patterns", <u>Journal of Applied Physiology</u>, vol. 19 (January 1964) pp. 75-82.

28. Maccagno, A. L., "New Methods for Evaluting Respiratory Functioning in Athletes", <u>The Journal of Sports Medicine and Physical Fitness</u>, vol. 4 (December 1964), pp. 204-207.

29. McKerrow, C. B., Otis, A. B., "Oxygen Cost of Hyperventilation", Journal of Applied Physiology, vol. 9 (1956), pp. 375-379.

30. Murray, J. F., "Oxygen Cost of Voluntary Hyperventilation", Journal of Applied Physiology, vol. 14 (1959), pp. 187-190.

31. Liljestrand, G., "Untersuchung Ueber die Atmungsarbeit", Skandinavisches Archiv Fuer Physiologie, vol. 35 (1917), pp. 199-293.

32. McKerrow, op. cit., p. 376.

33. Murray, op. cit., p. 188.

34. Otis, A. B., "The Work of Breathing", Physiological Reviews, vol. 34 (July 1954), pp. 449-458.

35. Nasset, E. S., Peters, S. B., "An Estimate of the Energy Requirement of Pulmonary Hyperventilation", The American Journal of Physiology, vol. 106 (November 1933), pp. 291-298.

36. McKerrow, op. cit., p. 378.

37. Christie, op. cit., p. 383.

38. Liljestrand, op. cit., pp. 251-253.

39. Milic-Emili, G., Petit, J. M., Peroanne, R., "Mechanical Work of Breathing During Exercise in Trained and Untrained Subjects", Journal of Applied Physiology, vol. 17 (1962), pp. 43-46.

40. Margaria, op. cit., p. 357.

CHAPTER IV

METHODS AND PROCEDURE

Introduction

Direct or indirect calorimetry is used to measure the production of heat or energy by the human body. Indirect calorimetry measures energy expenditure from determined amounts of oxygen consumed and is studied by either open or closed circuit methods.

Apparatus

The apparatus used in this study was a closed circuit chamber, (8' X 8' X 4'), with a gross volume of 6,900 litres, equipped with adequate lighting and viewing windows on two sides.[1] An air conditioning unit and high velocity fan controlled chamber temperature and humidity and assured uniform composition of air circulating in the chamber. Wet and dry temperatures were recorded at regular intervals. Air was continuously withdrawn from the chamber at a flow rate of 250 ml per minute, dried and passed through Beckman oxygen and carbon dioxide analyzers which constantly recorded gaseous concentrations against time.

Subjects

Experiments were made on three normal subjects whose physical characteristics are presented in Table I. Two subjects were Faculty members, the other a graduate student of the School of Physical Education at the

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1. Designed and built by Dr. H. R. Nordan of the Department of Zoology, University of British Columbia.

University of British Columbia. The body volume of each subject was obtained by hydrostatic weighing according to Behnke (1).

TABLE I

Body Characteristics

Subject	Age	Weight (lb)	Weight (kg)	Height (in)	Height (cm)	Volume (l)
EB	32	190	86.2	71	180	82.0
SB	41	184.5	83.6	74	188	79.7
HL	25	164.5	74.7	72	183	70.3

Step Exercise

The work task was a step exercise on an eighteen inch bench which was performed at rates of eighteen, twenty-four, thirty, thirty-six and forty steps per minute for ten minutes or until exhaustion. All subjects had considerable experience with step exercises hence learning was not a considered factor (2). Subjects exercised at each work level on each of two separate occasions with only the manner of breathing being altered each time. The breathing technique was randomly assigned to experimental occasions in order to eliminate any systematic error due to order of performance. During hyperventilated breathing, deep inhalations and forceful exhalations were emphasized while unregulated choices of combinations of breathing rate and tidal volume were made by the subjects during normal breathing. Attempts were made to exercise under equitable conditions at each experiment. Experiments were carried out between 2:30 and 5:30 p. m. Chamber temperature and humidity were kept constant from day to day.

Experimental Procedure

Prior to each exercise, a ten minute resting metabolic rate was recorded with the subject in the sitting position. This was followed by a ten minute step test, the given rate being governed by a metronome. On completion of the exercise the subject sat for a fifteen minute recovery period. All pertinent data was recorded on the Chamber Data Sheet (Appendix A).

Analysis of Data

The air volume of the chamber was calculated from the gross chamber volume minus the volume of the subject and of the step. Carpenter's Tables (3) were used to correct the air volume to STPD. Decrements of oxygen in the chamber air were obtained minute by minute from linear measures made on the record of the continuous graph. These were converted to percentages of chamber air volume and finally to the volume of oxygen used by the subject in performing the work task. The Beckman analyzer recorded carbon dioxide concentration in milliamps. A calibration curve (Appendix B) was used to obtain the increment of carbon dioxide expressed as a percentage of chamber air volume, which was then converted to the volume of carbon dioxide produced by the subjects in performing the work task. All linear measures were made with calipers and measured to an accuracy of one tenth of a millimeter. Procedures for calculating oxygen consumption and carbon dioxide elimination are illustrated in Appendixes C and D.

The Nature of Differentiation

Differentiation of the gross gaseous uptake curves determines the rate of gaseous interchange at any moment during the experiment. Thus the first derivative curves determine the velocity of oxygen uptake and carbon dioxide elimination and the second derivative curves determine the acceleration or rate of velocity in gaseous uptake. These derived curves are highly sensitive to changes in the primary curve and thus highlight even the slightest inflections in this curve (4). The time derivative curves based on gross values of oxygen consumption and carbon dioxide elimination were obtained from an IBM computer program.

Variability of Measures: Standard Deviation of Measures

An estimate of the standard deviation of the measures was made from repeated experiments on one subject at similar work loads to those used in the experiment. Because of the several individual errors compounded into the variability of the final oxygen consumption and carbon dioxide production values, due in part to human variability as well as to instrumentation and measurement error, this was the only feasible method of including them all.

REFERENCES

1. Behnke, A. R., Feen, B. G., Welham, L. C., "The Specific Gravity of Healthy Men", The Journal of the American Medical Association, vol. 118 (1942), pp. 295-498.

2. Taylor, H. L., "Exercise and Metabolism", Science and Medicine of Exercise and Sport, Ed. W. R. Johnson, New York, Harper and Brothers, 1960, p. 133.

3. Carpenter, T. M., Tables, Factors and Formulas for Computing Respiratory Exchange and Biological Transformations of Energy, Washington D. C., Carnegie Institute of Washington Publication 303 C, 1964.

4. Banister, E. W., "Cardiovascular Parameters Including The Time Derivatives of the Brachial Pulse Wave in the Assessment of Physical Condition and the Efficacy of Training Programs", Unpublished Ph.D Thesis, University of Illinois, 1964, p. 6.

CHAPTER V

RESULTS

Comparisons of gaseous exchange during normal and hyperventilated breathing are illustrated in individual graphs (Figures one to four) and summarized for three subjects in Table II.

Figure 1: 18 steps per minute

Neither the volume or the time course of oxygen consumption are altered by hyperventilated breathing. Maximal $\dot{V}O_2$ is 2.5 l/min and occurs between minutes seven and eight. Hyperventilated breathing results in slightly higher cumulative consumption at the end of the recovery period. Individual subjects show characteristically patterned curves.

Figure 1: 24 steps per minute

Subjects SRB and HL show rapid increases in oxygen consumption with the onset of exercise while hyperventilating. All subjects show earlier peaking of $\dot{V}O_2$ with an early onset in its decrement. The maximal $\dot{V}O_2$ is 3.5 l/min. Subject HL consumed slightly more oxygen during the hyperventilated exercise.

Figure 1: 30 steps per minute

Hyperventilated breathing results in a rapid increase of $\dot{V}O_2$; the maximal $\dot{V}O_2$ attained during exercise is diminished. Gross oxygen consumption at the end of exercise is greater during hyperventilated breathing.

Figure 2: 18 steps per minute

Hyperventilation does not modify carbon dioxide elimination in subjects EWB and SRB. HL shows increased carbon dioxide elimination with hyperventilated breathing. The maximal $\dot{V}CO_2$ is 1 litre per minute for all subjects. The course of carbon dioxide elimination appears to be highly individual.

Figure 2: 24 steps per minute

Hyperventilation results in increased carbon dioxide elimination for all subjects. Derivative curves follow comparable time courses irrespective of breathing technique. The technique of hyperventilation results in a greater elimination of carbon dioxide after ten minutes of exercise.

Figure 2: 30 steps per minute

Subjects show an earlier rise in $\dot{V}CO_2$. The individual maximal $\dot{V}CO_2$ are similar in magnitude and time of occurrence.

Figure 3: O_2, 36 steps per minute

The individual oxygen uptake patterns appear to be unaltered by the experimental variable. Cumulative VO_2 values for each subject at the end of the experiment are identical. Maximal $\dot{V}O_2$ values (5 l per min) indicate a maximal work task. However the time course of oxygen consumption does not indicate the attainment of a steady state.

<u>Figure 3</u>: CO_2, 36 steps per minute

The $\dot{V}CO_2$ increases with greater rapidity at the onset of exercise while hyperventilating. The time course of the derivative curves appear similar, irrespective of breathing technique. A maximal $\dot{V}CO_2$ of 4 l/min was attained during exercise. Subjects EWB and HL eliminated more CO_2 during experiments involving hyperventilation.

<u>Figure 4</u>: O_2, 40 steps per minute

Both subjects show an earlier increase of $\dot{V}O_2$ with the onset of exercise while hyperventilating. Maximal $\dot{V}O_2$ attained is greater and occurs later during normal breathing. The decrement of $\dot{V}O_2$ occurs earlier when utilizing hyperventilating techniques.

<u>Figure 4</u>: CO_2, 40 steps per minute

Hyperventilated breathing results in a greater elimination of carbon dioxide during exercise. The course of $\dot{V}CO_2$ during normal breathing appears delayed when compared to the results attained during hyperventilation.

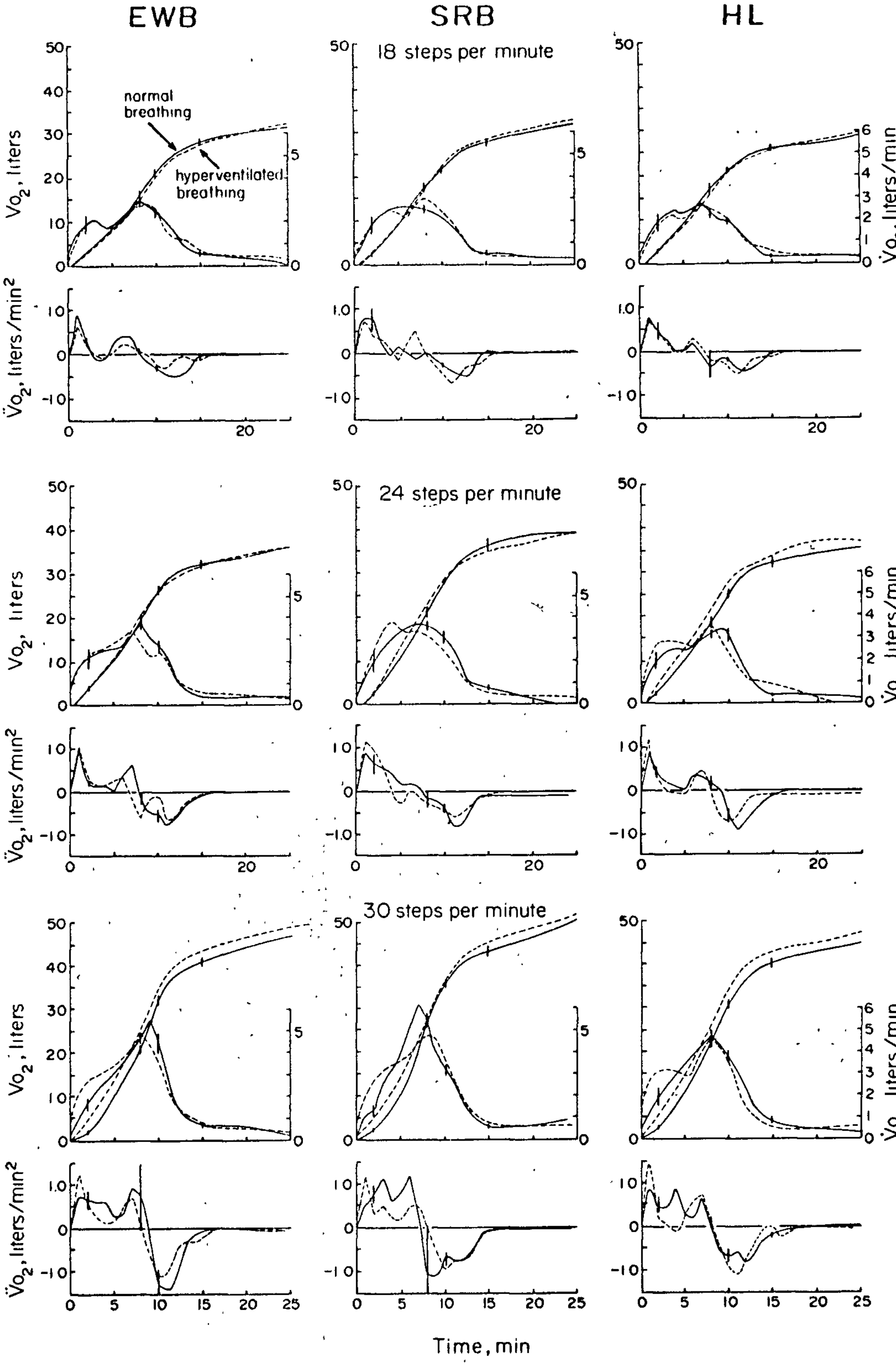


Figure 1. Gross oxygen consumption and derivative curves during normal and hyperventilated breathing at 18, 24 and 30 steps per minute.

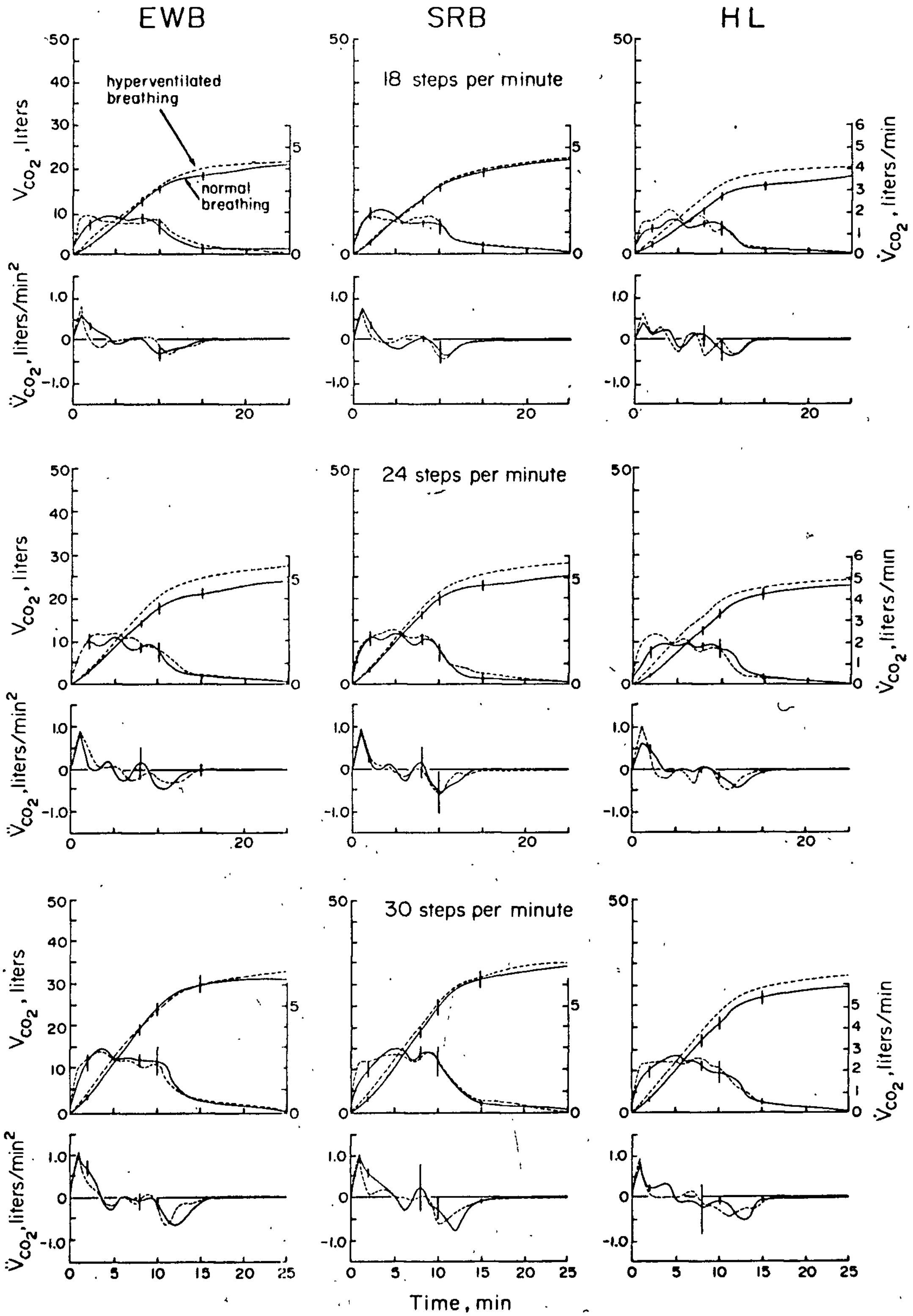


Figure 2. Gross carbon dioxide production and derivative curves during normal and hyperventilated breathing at 18, 24 and 30 steps per minute.

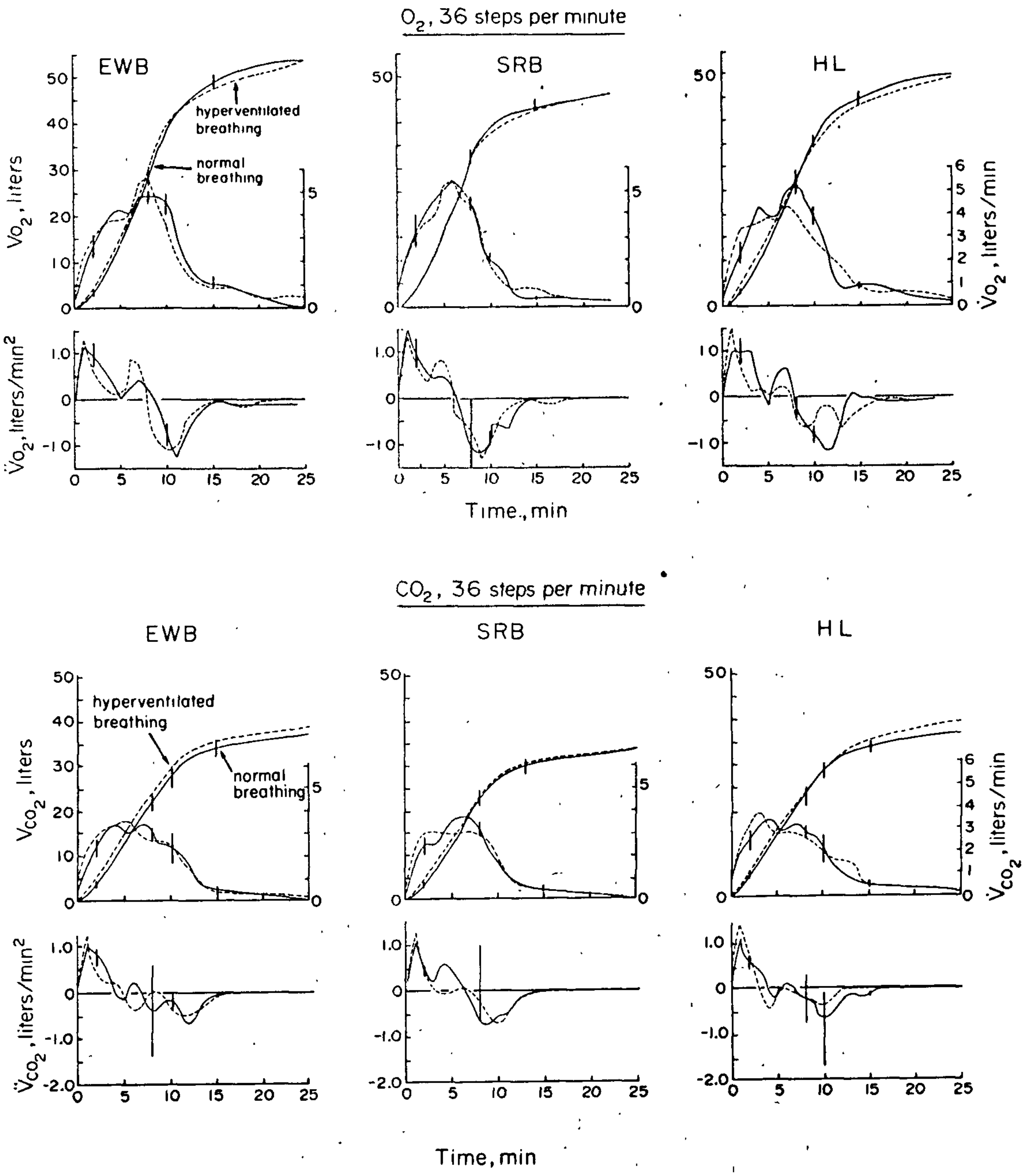


Figure 3. Gross oxygen consumption and carbon dioxide production curves and their derivatives during normal and hyperventilated breathing at 36 steps per minute.

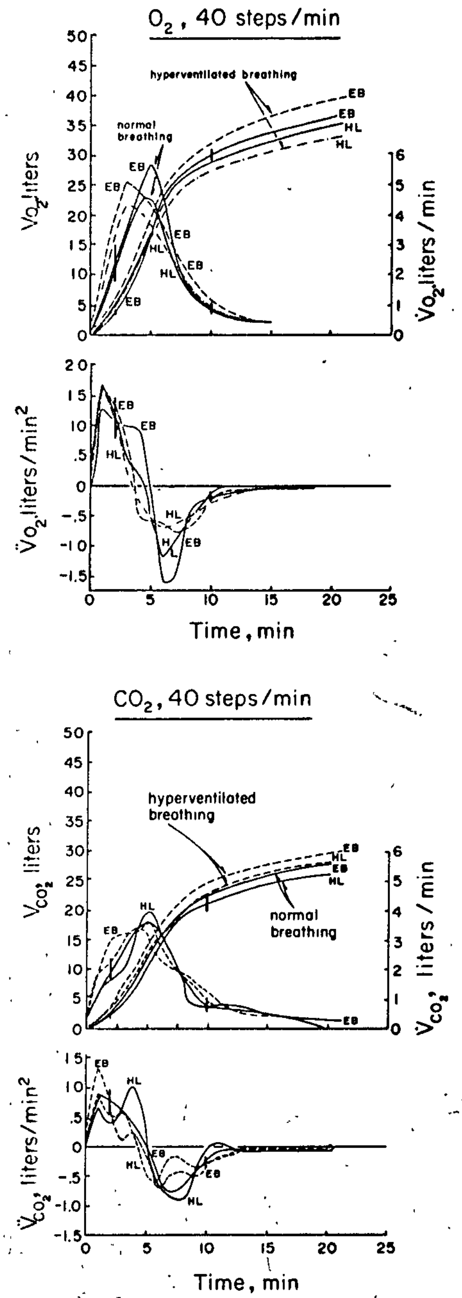


Figure 4. Gross oxygen consumption and carbon dioxide production curves and their derivatives during normal and hyperventilated breathing at 40 steps per minute.

TABLE II

Total Litres of Oxygen Consumed and Carbon Dioxide Produced by Three Subjects during the First Four Minutes of Exercise.

Work Level	Normal Breathing		Hyperventilated Breathing		Percent Difference	
	O_2 (l)	CO_2 (l)	O_2 (l)	CO_2 (l)	O_2	CO_2
18	21.10	16.24	19.17	19.35	90	119
24	23.72	19.93	28.77	24.47	122	122
30	19.93	23.81	33.97	28.78	171	120
36	31.77	28.01	34.80	33.70	109	121
40*	24.13	14.07	28.15	19.69	116	139

TABLE III

Total Litres of Oxygen Consumed and Carbon Dioxide Produced by Three Subjects during Fifteen Minute Recovery Period.

Work Level	Normal Breathing		Hyperventilated Breathing		Percent Difference	
	O_2 (l)	CO_2 (l)	O_2 (l)	CO_2 (l)	O_2	CO_2
18	28.33	16.45	31.58	17.35	111	106
24	30.43	17.97	29.38	18.72	96	104
30	44.06	28.10	41.76	26.33	94	93
36	42.66	27.32	43.91	30.65	102	113
40*	37.26	32.14	32.93	27.66	88	86

* result based on two subjects with duration of exercise 5 min during normal breathing and 5.5 min during hyperventilated breathing.

Table II

Gaseous exchange during the first four minutes of exercise is summarized in Table II. Hyperventilation increases oxygen consumption at all work tasks except 18 steps per minute. The greatest increase (71%) occurs at 30 steps per minute. Carbon dioxide elimination is increased at all work tasks during hyperventilated breathing.

Table III

A summary of gaseous interchange during fifteen minutes of recovery is presented in Table III. Hyperventilation tends to decrease oxygen consumption during recovery after exercise frequencies above 18 steps per minute. Stepping frequencies of 18, 24 and 36 steps per minute show increased carbon dioxide elimination during recovery following hyperventilation exercises.

CHAPTER VI

DISCUSSION

Results clearly indicate that hyperventilation does not alter the course of gaseous interchange at the lowest work level. It did however increase oxygen consumption and carbon dioxide elimination during recovery indicating that hyperventilation at low work levels serves no beneficial function. Rather it appears to be a useless circulation of air demanding increased work of the respiratory musculature, hence the increased oxygen consumption during recovery. At all other work levels the time derivative curves of oxygen uptake and carbon dioxide production emphasize that greater values of both parameters are obtained earlier during exercise with hyperventilated breathing. The oxygen consumption during the recovery period is decreased in almost all cases when the exercise was accompanied with hyperventilation. Krustev (1) utilizing a three minute workout followed by a minute's rest reported considerable increases in the oxygen intake both during the workout and the period of rest. This, he felt, reduced the oxygen debt and increased working capacity. Similar results were reported for carbon dioxide separation.

Andersen (2) has shown that the oxidative processes are slow to enter into play at the beginning of muscular exercise. Consequently a very short exercise is accomplished only or substantially at the expense of the high energy phosphate breakdown with the accompanying alactacid component. Morehouse (3) has found that the circulatory and respiratory adjustments that make possible a greater oxygen intake come into play gradually and in heavy work several minutes may be required for the oxygen intake to reach the level of the steady state. The greater $\dot{V}O_2$ attained during the early phases of exercise in these experiments may indicate an earlier onset of the oxidative processes during hyperventilated breathing. The oxygen consumption during recovery is a measure of the anaerobic activity during the exercise. The decreased oxygen consumption during recovery following hyperventilated exercises indicates increased oxidative processes during exercise. The exercise at 30 steps per minute resulted in the greatest increase of oxygen consumption during the first four minutes and was accompanied by the least amount of oxygen consumed during the recovery period.

Donevan (4) has shown that the effect of hyperventilation during exercise is one of increasing the cardiac output. This increase was more the result of an increase in heart rate rather than stroke volume. Oxygen uptake is considered to be influenced by two factors; the diffusing capacity of the lungs which is not considered to be significant at sea level, and the cardiac output. Thus the possibility of an earlier onset of the oxidative processes due to increased cardiac output does exist. Margaria (5) reports that cardiac output is the most likely limiting factor on maximum oxygen consumption. It is dependent on stroke volume and heart frequency. To substantiate these hypothesis, further hyperventilation experiments taking continuous pulse counts should be conducted.

If oxidative processes come into play earlier during hyperventilated exercise it would seem logical to assume that the activity could be sustained for a longer period of time. It is noteworthy that the two subjects who exercised at the exhaustive work rate of 40 steps / min subjectively felt more comfortable during the work task and one stepped for a full minute longer using the hyperventilation method.

No observations could be made on the effect of hyperventilation upon the individuals maximal oxygen consumption. The nature of the exercise did not allow a demonstration of this factor. Rovelli (6) and Andersen (7) state that the muscle mass used in this type of exercise intensity is limited by the amount of oxygen which may be carried from the heart to the exercising muscle mass. For this reason the step exercise is not suitable for the determination of maximal oxygen uptake. In none of the experiments was there any indication of the attainment of a steady state.

Expiration is the bottleneck of gaseous exchange (8). It is unacceptable to assume that the optimal duration, intensity and volume of respiration is brought about by the mechanical elastic force of the lungs and chest unassisted. Expiration is an active physiological process and can therefore be deliberately modified.

The gross curves and their derivatives clearly illustrate that individuals show characteristic curves of oxygen uptake and carbon dioxide elimination. Changing the breathing technique does not appear to alter the basic pattern of these curves. The possibility of utilizing individual curves to differentiate between various degrees of physical fitness is indicated.

REFERENCES

1. Krustev, K., "Oxygen and Sporting Achievement", Bulletin d'Information, Comite' Olympique Bulgare, vol. 5 (May 1963), pp. 26-28.

2. Andersen, K. L., "Measurements of Work Capacity", The Journal of Sports Medicine and Physical Fitness, vol. 4 (December 1964), pp. 236-240.

3. Morehouse, L. E., Miller, A. T., Physiology of Exercise, 4th ed., St. Louis, C. V. Mosby, 1963, p. 186.

4. Donevan, R. E., Anderson, N. M., Sekelj, P., Papp, O., McGregor, M., "Influence of Voluntary Hyperventilation on Cardiac Output", Journal of Applied Physiology, vol. 17 (May 1962), pp. 487-491.

5. Margaria, R., Mangili, F., Cuttica, F., Cerretelli, P., "The Kinetics of the Oxygen Consumption at the Onset of Muscular Exercise in Man", Ergonomics, vol. 8 (January 1965), pp. 49-54.

6. Rovelli, E., Aghemo, P., "Physiological Characteristics of the 'Step' Exercise", Int. Z. angew. Physiol. einschl. Arbeitsphysiol., vol. 20 (1963), pp. 190-194.

7. Andersen, op. cit., p. 238.

8. Krotev., L., "New Concept of Breathing", Bulletin d'Information, Comite' Olympique Bulgare, vol. 9 (December 1963), pp. 26-28.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary. This study was undertaken to determine and compare the rates of oxygen consumption and carbon dioxide elimination during normal and hyperventilated breathing at progressive work rates.

Three subjects performed step tests on an eighteen inch bench at 18, 24, 30, 36 and 40 steps per minute for a duration of ten minutes or until exhaustion. All exercises were performed inside a closed circuit respirometer equipped with Beckman oxygen and carbon dioxide analyzers as well as wet and dry thermocouples. Completion of the exercise was followed by a fifteen minute recovery period.

The chamber oxygen and carbon dioxide concentrations were continuously analyzed and recorded against time. Concentration values were converted to volumes of oxygen consumed (VO_2) and carbon dioxide elimated (VCO_2). An IBM computer program was used to determine the velocity ($\dot{V}O_2$, $\dot{V}CO_2$) and acceleration ($\ddot{V}O_2$, $\ddot{V}CO_2$) values. These values were plotted on graphs comparing the gaseous exchange during normal and hyperventilated breathing.

Conclusions. Hyperventilation increased the $\dot{V}O_2$ and $\dot{V}CO_2$ during the early phase of exercise at the higher work levels. This was followed by a decreased VO_2 during the recovery period. The possibility of an earlier onset of the oxidative processes during hyperventilated breathing is indicated. This possibility appears to be substantiated by related research. Hyperventilation during exercise has been shown to increase heart rate and hence cardiac output. This could result in an earlier onset of the oxidative processes. Individuals showed characteristic curves of oxygen uptake and carbon dioxide elimination. The possibility of utilizing individual curves as a physical fitness criterion is indicated.

BIBLIOGRAPHY

BOOKS

Carpenter, T. M., Tables, Factors and Formulas for Computing Respiratory Exchange and Biological Transformations of Energy, Washington D.C., Carnegie Institute of Washington Publication 303 C, 1964, pp. 147.

Garrett, H. E., Woodworth, R. S., Statistics In Psychology and Education, 5th ed., Toronto, Longmans, Green and Co., 1960, pp. 478.

Good, C. V., Scates, D. E., Methods of Research, New York, Appleton - Century - Crofts Inc., 1954, pp. 920.

Guyton, A. C., Textbook of Medical Physiology, second edition, Philadelphia, W. B. Saunders Co., 1961, pp. 1181.

Henderson, Y., Adventures in Respiration, Baltimore, The Williams and Wilkins Co., 1938, pp. 316.

Morehouse, L. E., Miller, A. T., Physiology of Exercise, 4th ed., St. Louis, C. V. Mosby, 1963, pp. 323.

Taylor, H. L., Science and Medicine of Exercise and Sports, New York, Harper and Brothers, 1960, p. 128.

PERIODICALS

Andersen, K. L., "Measurements of Work Capacity", The Journal of Sports Medicine and Physical Fitness, vol. 4 (December 1964), pp. 236-240.

Astrand, P. O., "Human Physical Fitness with Specific Reference to Age and Sex", Physiological Reviews, vol. 36 (July 1956), pp. 307-335.

Asmussen, E., Nielsen, M., "Studies on the Regulation of Respiration in Heavy Work", Acta Physiologica Scandinavica, vol. 12 (1946), pp. 171-187.

Balke, B., Lillehei, J. P., "Effect of Hyperventilation on Performance", Journal of Applied Physiology, vol. 9 (1956, pp. 371-374.

Bartlett, R. G., Bruback, H. F., Specht, H., "Oxygen Cost of Breathing", Journal of Applied Physiology, vol. 12 (1958), pp. 413-424.

Behnke, A. R., Feen, B. G., Welham, L. C., "The Specific Gravity of Healthy Men", The Journal of the American Medical Association, vol. 118 (1942), pp. 295-498.

Christie, R. V., "Dypnoea in Relation to the Visco-Elastic Properties of the Lung", Proceedings of the Royal Society of Medicine, vol. 46 (May 1953), pp. 381-386.

Comroe, J. H., "The Hyperpnea of Muscular Exercise", Physiological Reviews, vol. 24 (July 1944), pp. 319-339.

Donevan, R. E., Anderson, N. M., Sekelj, P., Papp, O., McGregor, M., "Influence of Voluntary Hyperventilation on Cardiac Output", Journal of Applied Physiology, vol. 17 (May 1962), pp. 487-491.

Grodins, F. S., "Analysis of Factors Concerned in Regulation of Breathing in Exercise", Physiological Reviews, vol. 30 (April 1950), pp. 220-239.

Hickam, J. B., Pryor, W. W., Page, E. B., Atwell, R. J., "Respiratory Regulation During Exercise in Unconditioned Subjects", Journal of Clinical Investigation, vol. 30 (May 1951), pp. 503-516.

Krogh, A., Lindhard, J., "The Regulation of Respiration and Circulation During the Initial Stages of Muscular Work", Journal of Physiology, vol. 47 (October 1913), pp. 112-136.

Krotev, L., "New Concept of Breathing", Bulletin d'Information, Comite' Olympique Bulgare, vol. 9 (December 1963), pp. 26-28.

Krumholz, R. A., Ross, J. C., "Secondary Ventilatory Response to Exercise Modiciations by Agents which Alter CBF", Journal of Applied Physiology, vol. 20 (March 1965), pp. 257-262.

Krustev, K., "Oxygen and Sporting Achievement", Bulletin d'Information, Comite' Olympique Bulgare, vol. 5 (May 1963), pp. 26-28.

Lamb, T. W., Anthonisen, N. R., Tenney, S. M., "Controlled Frequency Breathing During Muscular Exercise", Journal of Applied Physiology, vol. 20 (March 1965), pp. 244-248.

Leblanc, J. A., "Use of Heart Rate as an Index of Work Output", Journal of Applied Physiology, vol. 10 (March 1957), pp. 275-280.

Liljestrand, G., "Untersuchung Ueber die Atmungsarbeit", Skandinavisches Archiv Fuer Physiologie, vol. 35 (1917), pp. 199-293.

McKerrow, C. B., Otis, A. B., "Oxygen Cost of Hyperventilation", Journal of Applied Physiology, vol. 9 (1956), pp. 375-379.

Maccagno, A. L., "New Methods for Evaluating Respiratory Functioning in Athletes", The Journal of Sports Medicine and Physical Fitness, vol. 4 (December 1964), pp. 204-207.

Margaria, R. Milic-Emeli, G., Petit, J. M., Cavagna, G., "Mechanical Work of Breathing during Muscular Exercise", Journal of Applied Physiology, vol. 15 (May 1960), pp. 354-358.

Margaria, R., Mangili, F., Cuttica, F., Corretelli, P., "The Kinetics of the Oxygen Consumption at the Onset of Muscular Exercise in Man", Ergonomics, vol. 8 (January 1965), pp. 49-54.

Mead, J., "Control of Respiratory Frequency", Journal of Applied Physiology, vol. 15 (May 1960), pp. 325-336.

Miles, W. K., "Oxygen Consumption During Three Yoga-type Breathing Patterns", Journal of Applied Physiology, vol. 19 (January 1964) pp. 75-82.

Milic-Emili, G., Petit, J. M., Peroanne, R., "Mechanical Work of Breathing During Exercise in Trained and Untrained Subjects", Journal of Applied Physiology, vol. 17 (1962), pp. 43-46.

Mitchell, J., Sproule, B. J., Chapman, C. B., "Factors Influencing Respiration During Heavy Exercise", Journal of Clinical Investigation, vol. 37 (1958), pp. 1693-1701.

Murray, J. F., "Oxygen Cost of Voluntary Hyperventilation", Journal of Applied Physiology, vol. 14 (1959), pp. 187-190.

Nasset, E. S., Peters, S. B., "An Estimate of The Energy Requirement of Pulmonary Hyperventilation", The American Journal of Physiology, vol. 106 (November 1933), pp. 291-298.

Otis, A. B., "Physiology of Respiration in Relation to Environment and to Muscular Exercise", The Journal of Sports Medicine and Physical Fitness, vol. 2 (June 1962), pp. 83-85.

Otis, A. B., "The Work of Breathing", Physiological Reviews, vol. 34 (July 1954), pp. 449-458.

Ramanathan, N. L., "Reliability of Estimation of Metabolic Levels from Respiratory Frequency", Journal of Applied Physiology, vol. 19 (May 1964), pp. 497-502.

Riley, R. L., "The Work of Breathing and Its Relation to Respiratory Acidosis", Annals of Internal Medicine, vol. 41 (1954), pp. 172-176.

Rovelli, E., Aghemo, P., "Physiological Characteristics of the 'Step' Exercise", Int. Z. angew. Physiol. einschl. Arbeitsphysiol., vol. 20 (1963), pp. 190-194.

Shapiro, W., Johnston, C. E., Dameron, B. A., Patterson, J. B., "Maximum Ventilatory Performance and its Limiting Factors", Journal of Applied Physiology, vol. 19 (March 1964), pp. 199-203.

Slonim, N. B., Gillespie, D. G., Harold, H. H., "Peak Oxygen Uptake of Healthy Young Men as Determined by a Treadmill Method", Journal of Applied Physiology, vol. 10 (1957), pp. 401-404.

Storey, W. F., Butler, J., "Evidence That the PCO_2 of Mixed Venous Blood is Not a Regulator of Ventilation During Exercise", Journal of Applied Physiology, vol. 18 (March 1963), pp. 345-348.

Torelli, G., Brandi, G., "The Hyperventilation in the First 15 Seconds of Muscular Work", The Journal of Sports Medicine and Physical Fitness, vol. 4 (March 1964), pp. 25-27.

Torelli, G., Brandi, G., "The Components of Nervous Regulation of the Ventilation", The Journal of Sports Medicine and Physical Fitness, vol. 4 (June 1964), pp. 75-78.

UNPUBLISHED MATERIAL

Banister, E. W., "Cardiovascular Parameters Including The Time Derivatives of the Brachial Pulse Wave in the Assessment of Physical Condition and the Efficacy of Training Programs", Unpublished Ph. D. Dissertation, University of Illinois, 1964, pp. 1-92.

APPENDIX

APPENDIX A

CHAMBER DATA SHEET

DATE ______________ NAME ______________________

EXERCISE ______________________

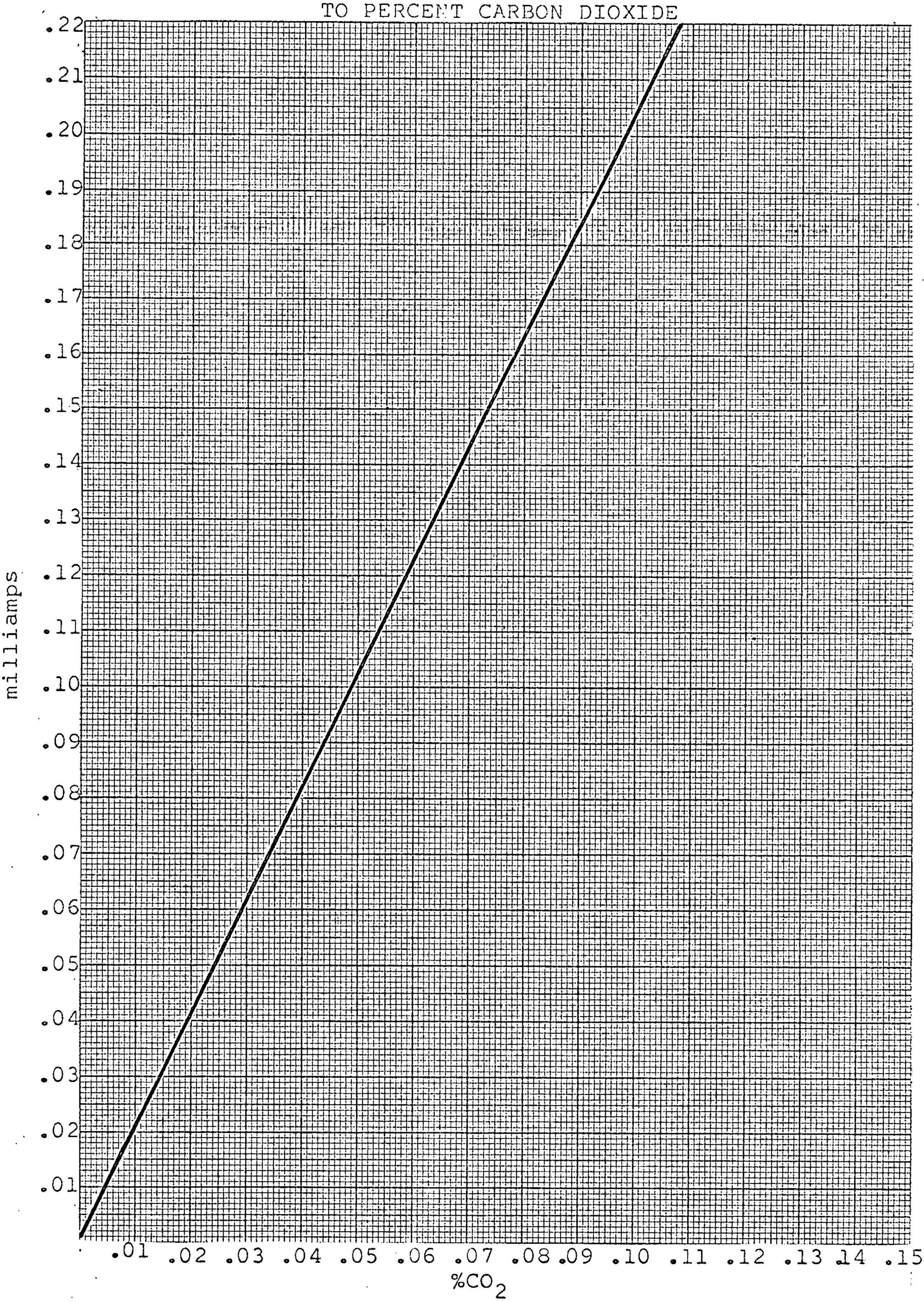
Resting H.R. _____ x 4 _____
Terminal H.R. _____ x 4 _____
" " " 1 min. _____ x 4 _____
" " " 2 min. _____ x 4 _____
" " " 3 min. _____ x 4 _____
" " " 4 min. _____ x 4 _____
" " " 5 min. _____ x 4 _____
Terminal after 15 min. _____ x 4 _____

Temp. Wet _____
" Dry _____
Pressure _____

Volume _____
Corrected Volume _____

	Time	% O_2	CO_2 Amp	CO_2 %	Corr. Vol.	VO_2	VCO_2
Basal							
Exercise Period	1 min.						
	2 min.						
	3 min.						
	4 min.						
	5 min.						
	6 min.						
	7 min.						
	8 min.						
	9 min.						
	10 min.						
Recovery Period	11 min.						
	12 min.						
	13 min.						
	14 min.						
	15 min.						
	–						
	18 min.						
	–						
	21 min.						
	–						
	–						
	25 min.						

CALIBRATION CURVE FOR CONVERSION OF MILLIAMPS TO PERCENT CARBON DIOXIDE



APPENDIX C

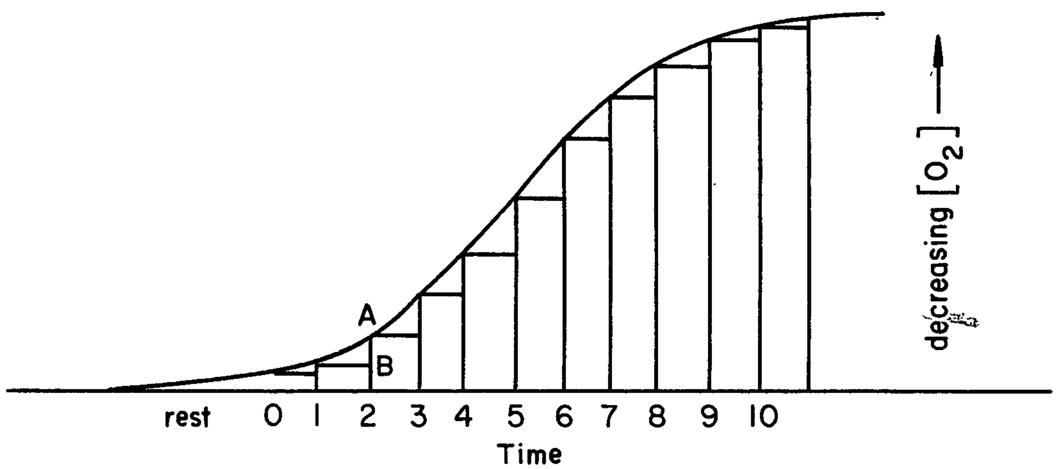
PROCEDURE FOR CALCULATION OF OXYGEN CONSUMPTION

Correction of chamber volume to STPD.

$$V_{initial} = \text{Chamber volume} - (\text{subject volume} + \text{volume of step})$$

$$V_{corrected} = V_{initial} \times \frac{P_{atm} - P_{water\ vapor}}{760} \times \frac{273\ °K}{\text{Temp}\ (°K)}$$

Conversion of linear distance to percentage oxygen consumed.



Measure AB in mm with Vernier calipers

1 division represents .04% ΔVO_2*

10 divisions = x mm

$$1\ \text{mm} = \frac{10}{x}\ \text{divisions}$$

$$K = \frac{10}{x} \times .04\%\ \Delta VO_2$$

linear measure x K = % ΔVO_2

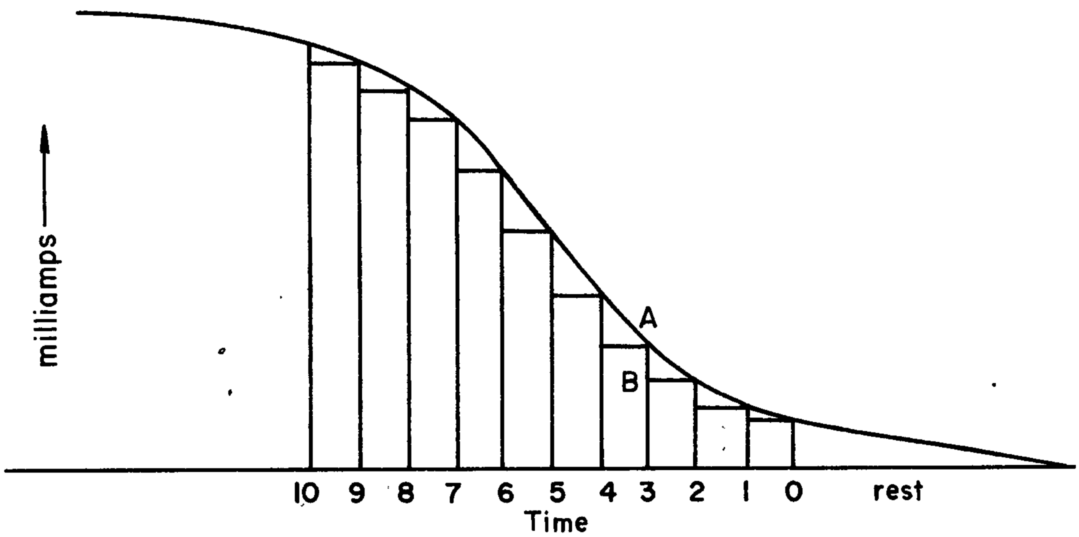
$\%\Delta VO_2 \times V_{corrected} = VO_2$ consumed

* ΔVO_2 represents decrement in oxygen concentration.

APPENDIX D

PROCEDURE FOR CALCULATION OF CARBON DIOXIDE ELIMINATION

Conversion of linear measure to milliamps.



Measure AB in mm with Vernier calipers

1 division = .1 ma

10 divisions = x mm

$1 \text{ mm} = \frac{10}{x} \times .1 \text{ ma}$

$K = \frac{10}{x} \times .1 \text{ ma}$

K x linear measure = ma

Use calibration curve (APPENDIX B) for conversion of milliamps to % CO_2

$\% \Delta CO_2{}^{*} \times V_{corrected} = VCO_2$ eliminated

* ΔCO_2 represents increment in carbon dioxide concentration.

APPENDIX E

RAW SCORES FOR ALL SUBJECTS ON ALL TEST ITEMS

TABLE IV

Gross and Derivative Values for Subject EB
at 18 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.31	0.	0.	0.34	0.	0.	0.29	0.	0.	0.32	0.
1	1.01	1.50	0.82	0.50	0.97	0.58	0.87	1.14	0.77	1.40	1.70	0.78
2	3.01	1.95	0.28	1.94	1.50	0.33	2.28	1.84	0.46	3.40	1.88	-0.06
3	4.90	2.06	-0.08	3.50	1.62	0.16	4.55	2.06	0.00	5.16	1.58	-0.18
4	7.14	1.78	-0.14	5.18	1.81	0.06	6.40	1.84	-0.16	6.56	1.52	-0.05
5	8.47	1.78	0.19	7.12	1.75	-0.12	8.25	1.74	0.05	8.19	1.48	-0.05
6	10.70	2.17	0.42	8.68	1.56	-0.06	9.87	1.95	0.43	9.51	1.42	-0.01
7	12.82	2.62	0.39	10.24	1.62	0.06	12.15	2.60	0.38	11.03	1.46	-0.01
8	15.94	2.95	0.03	11.93	1.69	-0.00	15.08	2.71	0.11	12.43	1.40	0.06
9	18.73	2.68	-0.22	13.61	1.62	-0.20	17.57	2.82	-0.03	13.82	1.58	0.09
10	21.29	2.51	-0.31	15.17	1.28	-0.34	20.72	2.65	-0.54	15.58	1.58	-0.20
11	23.75	2.06	-0.50	16.17	0.94	-0.30	22.88	1.73	-0.68	16.98	1.18	-0.36
12	25.42	1.50	-0.53	17.05	0.69	-0.25	24.18	1.30	-0.24	17.95	0.85	-0.26
13	26.75	1.00	-0.45	17.55	0.44	-0.19	25.48	1.24	-0.11	18.68	0.67	-0.18
14	27.42	0.61	-0.22	17.92	0.31	-0.09	26.67	1.08	-0.24	19.29	0.49	-0.15
15	27.98	0.56	-0.04	18.17	0.25	-0.03	27.65	0.76	-0.27	19.67	0.36	-0.08
16	28.53	0.53	-0.03	18.41	0.25	0.00	28.19	0.53	-0.12	20.02	0.33	-0.03
17	29.05	0.48	-0.04	18.67	0.25	0.00	28.72	0.52	-0.01	20.33	0.30	-0.03
18	29.51	0.45	-0.04	18.92	0.25	0.00	29.23	0.51	-0.01	20.61	0.26	-0.03
19	29.96	0.40	-0.04	19.18	0.25	0.00	29.74	0.50	-0.01	20.86	0.23	-0.03
20	30.31	0.36	-0.04	19.43	0.26	0.00	30.23	0.49	-0.01	21.08	0.20	-0.03
21	30.65	0.31	-0.04	19.69	0.26	0.00	30.71	0.48	-0.01	21.26	0.17	-0.03
22	30.94	0.27	-0.04	19.95	0.26	0.00	31.18	0.46	-0.01	21.41	0.13	-0.03
23	31.19	0.22	-0.04	20.21	0.26	0.00	31.64	0.45	-0.01	21.52	0.10	-0.03
24	31.39	0.18	0.04	20.47	0.26	0.03	32.09	0.44	-0.08	21.61	0.07	0.11
25	31.54	0.31	0.	20.72	0.34	0.	32.52	0.29	0.	21.65	0.31	0.

TABLE V

Gross and Derivative Values for Subject SB
at 18 steps per min

Time	Normal Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	Hyperventilated Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.34	0.	0.	0.39	0.	0.	0.36	0.	0.	0.32	0.
1	0.67	1.00	0.78	0.87	1.34	0.74	0.75	1.24	0.71	1.21	1.47	0.71
2	2.01	1.90	0.78	2.69	1.87	0.33	2.48	1.78	0.40	2.96	1.75	0.08
3	4.46	2.57	0.22	4.62	1.00	0.03	4.31	2.05	0.35	4.70	1.63	-0.06
4	7.14	2.34	-0.06	6.68	1.94	-0.16	6.58	2.48	0.13	6.22	1.63	-0.08
5	9.15	2.45	0.17	8.49	1.69	-0.27	9.27	2.31	-0.19	7.97	1.47	-0.08
6	12.04	2.68	0.00	10.05	1.41	-0.14	11.20	2.10	0.27	9.17	1.47	0.10
7	14.50	2.46	-0.14	11.30	1.41	0.00	13.47	2.85	0.48	10.92	1.69	0.11
8	16.95	2.40	-0.03	12.86	1.41	0.03	16.91	3.07	-0.05	12.55	1.69	0.06
9	19.20	2.40	-0.11	14.11	1.47	-0.	19.60	2.74	-0.27	14.30	1.81	-0.11
10	21.75	2.18	-0.31	15.80	1.41	-0.30	22.40	2.53	-0.48	16.17	1.47	-0.45
11	23.65	1.79	-0.36	16.92	0.87	-0.39	24.67	1.77	-0.67	27.26	0.91	-0.41
12	25.32	1.45	-0.50	17.55	0.62	-0.17	25.96	1.18	-0.40	17.98	0.66	-0.18
13	26.55	0.78	-0.53	18.17	0.54	-0.09	27.04	0.97	-0.27	18.59	0.54	-0.10
14	26.88	0.39	-0.14	18.62	0.43	-0.06	27.90	0.65	-0.27	19.07	0.47	-0.05
15	27.33	0.50	0.07	19.04	0.41	-0.03	28.32	0.43	-0.10	19.52	0.44	-0.03
16	27.88	0.54	0.01	19.43	0.38	-0.03	28.76	0.43	0.00	19.94	0.41	-0.03
17	28.41	0.52	-0.03	19.80	0.35	-0.03	29.19	0.44	0.01	20.33	0.37	-0.03
18	28.91	0.49	-0.03	20.13	0.32	-0.03	29.63	0.44	0.01	20.69	0.34	-0.03
19	29.39	0.46	-0.03	20.45	0.20	-0.03	30.07	0.45	0.01	21.02	0.31	-0.03
20	29.84	0.43	-0.03	20.73	0.27	-0.03	30.52	0.45	0.01	21.31	0.28	-0.03
21	30.26	0.41	-0.03	20.99	0.24	-0.03	30.98	0.45	0.01	21.58	0.25	-0.03
22	30.65	0.38	-0.03	21.22	0.21	-0.03	31.44	0.46	0.01	21.81	0.22	-0.03
23	31.02	0.35	-0.03	21.42	0.19	-0.03	31.91	0.47	0.01	22.01	0.19	-0.03
24	31.36	0.32	-0.01	21.60	0.16	0.10	32.38	0.47	-0.06	22.19	0.16	0.07
25	31.67	0.34	0.	21.74	0.38	0.	32.85	0.36	0.00	22.33	0.33	0.

TABLE VI

Gross and Derivative Values for Subject HL
at 18 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.29	0.	0.	0.42	0.	0.	0.30	0.	0.	0.30	0.
1	0.78	1.23	0.78	0.75	1.00	0.38	0.87	1.03	0.69	1.40	1.52	0.61
2	2.46	1.84	0.47	2.00	1.18	0.09	2.06	1.68	0.52	3.04	1.52	0.12
3	4.47	2.18	0.28	3.13	1.19	0.20	4.23	2.06	0.24	4.44	1.76	0.27
4	6.82	2.40	0.06	4.38	1.60	0.20	6.19	2.17	0.00	6.57	2.06	-0.03
5	9.28	2.29	0.03	6.32	1.60	-0.20	8.58	2.06	0.03	8.57	1.70	-0.33
6	11.40	2.46	0.20	7.58	1.19	-0.16	10.31	2.23	0.30	9.98	1.40	0.06
7	14.20	2.68	-0.08	8.70	1.28	0.13	13.03	2.66	0.14	11.37	1.82	0.14
8	16.77	2.29	-0.36	10.14	1.44	0.11	15.64	2.50	-0.19	13.62	1.67	-0.40
9	18.78	1.96	-0.17	11.58	1.50	-0.05	18.03	2.28	-0.22	14.72	1.03	-0.24
10	20.68	1.96	-0.17	13.14	1.35	-0.28	20.20	2.06	-0.35	15.69	1.19	0.02
11	22.69	1.62	-0.42	14.28	0.94	-0.42	22.15	1.57	-0.52	17.09	1.06	-0.32
12	23.92	1.12	-0.45	15.03	0.50	-0.35	23.34	1.03	-0.38	17.82	0.56	-0.36
13	24.93	0.73	-0.36	15.28	0.25	-0.13	24.21	0.82	-0.16	18.19	0.35	-0.11
14	25.37	0.39	-0.19	15.53	0.25	-0.00	24.97	0.71	-0.14	18.53	0.33	-0.02
15	25.71	0.34	-0.03	15.77	0.25	-0.00	25.62	0.54	-0.14	18.85	0.31	-0.02
16	26.05	0.34	-0.00	16.02	0.24	-0.00	26.05	0.43	-0.06	19.15	0.29	-0.02
17	26.38	0.33	-0.01	16.26	0.24	-0.00	26.48	0.42	-0.01	19.42	0.26	-0.02
18	26.71	0.32	-0.01	16.50	0.24	-0.00	26.89	0.41	-0.01	19.67	0.24	-0.02
19	27.03	0.32	-0.01	16.73	0.23	-0.00	27.29	0.40	-0.01	19.90	0.22	-0.02
20	27.35	0.31	-0.01	16.97	0.23	-0.00	27.69	0.40	-0.01	20.11	0.20	-0.02
21	27.66	0.31	-0.01	17.20	0.23	-0.00	28.08	0.38	-0.01	20.30	0.17	-0.02
22	27.96	0.30	-0.01	17.43	0.23	-0.00	28.45	0.37	-0.01	20.45	0.15	-0.02
23	28.26	0.30	-0.01	17.65	0.22	-0.00	28.82	0.36	-0.01	20.59	0.13	-0.02
24	28.55	0.29	-0.00	17.87	0.22	0.10	29.18	0.35	-0.03	20.71	0.10	0.09
25	28.84	0.29	0.	18.09	0.43	0.	29.53	0.30	0.	20.80	0.30	0.

TABLE VII

Gross and Derivative values for subject EB
at 24 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.28	0.	0.	0.29	0.	0.	0.28	0.	0.	0.34	0.
1	1.22	1.84	0.98	1.00	1.59	0.85	1.20	1.75	1.04	1.11	1.44	0.90
2	3.68	2.23	0.22	3.18	2.00	0.08	3.51	2.36	0.36	2.89	2.15	0.46
3	5.68	2.29	0.14	5.00	1.75	-0.03	5.92	2.47	0.15	5.41	2.33	0.06
4	8.25	2.51	0.14	6.68	1.94	0.22	8.45	2.63	0.16	7.56	2.27	0.03
5	10.70	2.57	0.03	8.87	2.19	-0.03	11.19	2.80	0.27	9.95	2.40	0.06
6	13.38	2.57	0.39	11.05	1.87	-0.31	14.04	3.18	0.33	12.35	2.40	-0.09
7	15.84	3.35	0.61	12.61	1.56	-0.09	17.55	3.46	-0.19	14.75	2.21	-0.28
8	20.08	3.79	-0.14	14.17	1.69	0.16	20.95	2.80	-0.60	16.77	1.84	-0.22
9	23.42	3.07	-0.53	15.98	1.87	-0.05	23.14	2.25	-0.16	18.43	1.78	-0.09
10	26.21	2.73	-0.50	17.92	1.59	-0.44	25.45	2.47	-0.11	20.34	1.66	-0.23
11	28.89	2.06	-0.78	19.17	1.00	-0.48	28.08	2.03	-0.63	21.75	1.32	-0.31
12	30.34	1.17	-0.67	19.92	0.62	-0.28	29.51	1.21	-0.58	22.98	1.04	-0.32
13	31.23	0.72	-0.34	20.42	0.44	-0.12	30.50	0.88	-0.27	23.84	0.68	-0.28
14	31.78	0.50	-0.17	20.79	0.39	-0.02	31.27	0.66	-0.17	24.33	0.48	-0.12
15	32.23	0.39	-0.18	21.20	0.40	-0.01	31.81	0.55	-0.06	24.79	0.44	-0.03
16	32.56	0.34	-0.02	21.59	0.37	-0.02	32.36	0.53	-0.02	25.22	0.41	-0.03
17	32.92	0.36	0.01	21.95	0.35	-0.02	32.88	0.51	-0.02	25.62	0.38	-0.03
18	33.28	0.37	0.01	22.29	0.33	-0.02	33.38	9.49	-0.02	25.98	0.50	-0.03
19	33.66	0.39	0.01	22.60	0.30	-0.02	33.86	0.46	-0.02	26.31	0.31	-0.03
20	34.06	0.40	0.01	22.90	0.28	-0.02	34.31	0.44	-0.02	26.62	0.29	-0.03
21	34.46	0.42	0.01	23.17	0.26	-0.02	34.73	0.41	-0.02	26.89	0.25	-0.03
22	34.89	0.43	0.01	23.42	0.24	-0.02	35.14	0.39	-0.02	27.12	0.22	-0.03
23	35.32	0.44	0.01	23.64	0.21	-0.02	35.52	0.37	-0.02	27.33	0.19	-0.03
24	35.78	0.46	-0.08	23.84	0.19	0.04	35.87	0.34	-0.04	27.51	0.16	0.08
25	36.24	0.28	0.	24.02	0.29	0.	36.20	0.28	0.	27.65	0.34	0.

TABLE VIII

Gross and Derivative values for subject SB
at 24 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.34	0.	0.	0.34	0.	0.	0.33	0.	0.	0.34	0.
1	0.67	1.34	0.87	1.13	1.73	0.93	0.99	1.54	1.15	1.41	1.84	0.97
2	2.69	2.07	0.62	3.45	2.20	0.17	3.07	2.63	0.99	3.69	2.27	0.25
3	4.82	2.58	0.53	5.53	2.07	-0.	6.26	3.51	0.58	5.96	2.34	0.09
4	7.84	3.14	0.39	7.60	2.20	0.16	10.10	3.79	-0.08	8.36	2.46	0.09
5	11.10	3.37	0.14	9.92	2.39	-0.03	13.83	3.35	-0.28	10.88	2.52	-0.09
6	14.58	3.42	0.17	12.37	2.14	-0.28	16.79	3.24	-0.00	13.40	2.27	-0.18
7	17.94	3.70	0.08	14.19	1.82	-0.03	20.30	3.35	-0.08	15.43	2.15	-0.00
8	21.98	3.59	-0.10	16.01	2.07	0.16	23.49	3.07	-0.30	17.70	2.27	-0.03
9	25.12	3.30	-0.20	18.34	2.14	-0.20	26.45	2.74	-0.33	19.98	2.09	-0.41
10	28.60	3.20	-0.39	20.28	1.48	-0.57	28.98	2.42	-0.44	21.88	1.45	-0.58
11	31.51	2.52	-0.81	21.29	1.01	-0.42	31.28	1.87	-0.58	22.87	0.92	-0.29
12	33.64	1.57	-0.78	22.29	0.62	-0.38	32.71	1.26	-0.49	23.73	0.86	-0.09
13	34.65	0.96	-0.36	22.55	0.25	-0.19	33.81	0.88	-0.30	24.59	0.74	-0.15
14	35.56	0.86	-0.10	22.80	0.25	-0.00	34.47	0.66	-0.17	25.20	0.56	-0.13
15	36.37	0.76	-0.10	23.04	0.25	-0.00	35.12	0.55	-0.11	25.70	0.48	-0.06
16	37.07	0.65	-0.10	23.29	0.24	-0.00	35.56	0.43	-0.06	26.16	0.43	-0.05
17	37.67	0.55	-0.10	23.53	0.24	-0.00	35.99	0.43	-0.01	26.57	0.39	-0.05
18	38.17	0.45	-0.10	23.77	0.24	-0.00	36.41	0.41	-0.01	26.93	0.34	-0.05
19	38.57	0.35	-0.10	24.01	0.24	-0.00	36.83	0.41	-0.01	27.25	0.29	-0.05
20	38.87	0.24	-0.10	24.24	0.23	-0.00	37.24	0.41	-0.01	27.52	0.25	-0.05
21	39.06	0.14	-0.10	24.47	0.23	-0.00	37.64	0.40	-0.01	27.75	0.20	-0.05
22	39.15	0.04	-0.10	24.70	0.23	-0.00	38.03	0.39	-0.01	27.98	0.16	-0.05
23	39.14	0.06	-0.10	24.93	0.22	-0.00	38.42	0.39	-0.01	28.06	0.11	-0.05
24	39.02	0.17	0.20	25.15	0.22	0.06	38.81	0.38	-0.03	28.15	0.06	0.12
25	38.80	0.34	0.	25.37	0.34	0.	39.18	0.33	0.	28.19	0.34	0.

TABLE IX

Gross and Derivative Values for Subject HL
at 24 steps per min

Time	Normal Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	Hyperventilated Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.34	0.	0.	0.31	0.	0.	0.34	0.	0.	0.30	0.
1	0.79	1.57	0.90	0.63	0.94	0.61	1.69	2.24	1.29	1.45	1.89	1.05
2	3.14	2.13	0.34	1.88	1.54	0.47	4.49	2.92	0.31	3.77	2.39	0.25
3	5.05	2.25	0.20	3.71	1.88	0.17	7.52	2.86	-0.05	6.22	2.39	-0.19
4	7.63	2.52	0.08	5.65	1.88	-0.06	10.22	2.81	-0.06	8.55	2.01	-0.22
5	10.10	2.41	0.06	7.47	1.76	0.00	13.14	2.75	-0.08	10.25	1.95	0.06
6	12.45	2.63	0.34	9.17	1.88	0.00	15.72	2.64	0.25	12.45	2.14	-0.09
7	15.37	3.08	0.31	11.24	1.76	-0.06	18.42	3.26	0.45	14.53	1.76	-0.31
8	18.62	3.25	0.17	12.69	1.76	0.06	22.24	3.54	-0.14	15.97	1.51	-0.
9	21.88	3.42	-0.00	14.76	1.88	-0.03	25.49	2.98	-0.62	17.54	1.76	0.05
10	25.46	3.25	-0.59	16.46	1.79	-0.16	28.19	2.31	-0.73	19.49	1.60	-0.35
11	28.38	2.24	-0.92	18.15	1.57	-0.30	30.10	1.52	-0.59	20.75	1.07	-0.49
12	29.95	1.40	-0.67	19.60	1.10	-0.47	31.23	1.13	-0.23	21.63	0.63	-0.35
13	31.18	0.90	-0.48	20.35	0.63	-0.33	32.35	1.07	-0.09	22.01	0.36	-0.14
14	31.74	0.45	-0.25	20.85	0.43	-0.14	33.36	0.95	-0.12	22.36	0.34	-0.02
15	32.07	0.39	-0.01	21.21	0.35	-0.06	34.25	0.83	-0.12	22.69	0.31	-0.02
16	32.52	0.44	0.01	21.54	0.32	-0.03	35.02	0.71	-0.12	22.99	0.29	-0.02
17	32.95	0.42	-0.02	21.85	0.29	-0.03	35.67	0.59	-0.12	23.27	0.26	-0.02
18	33.35	0.40	-0.02	22.12	0.26	-0.03	36.21	0.47	-0.12	23.52	0.24	-0.02
19	33.74	0.38	-0.02	22.37	0.23	-0.03	36.62	0.36	-0.12	23.75	0.21	-0.02
20	34.11	0.36	-0.02	22.58	0.20	-0.03	36.92	0.24	-0.12	23.95	0.19	-0.02
21	34.46	0.34	-0.02	22.77	0.17	-0.03	37.10	0.12	-0.12	24.13	0.16	-0.02
22	34.79	0.32	-0.02	22.93	0.15	-0.03	37.16	0.00	-0.12	24.28	0.14	-0.02
23	35.10	0.30	-0.02	23.06	0.12	-0.03	37.10	0.12	-0.12	24.41	0.12	-0.02
24	35.39	0.28	0.02	23.17	0.09	0.10	36.92	0.24	0.23	24.51	0.09	0.09
25	35.66	0.34	0.	23.24	0.31	0.	36.62	0.34	0.	24.59	0.30	0.

TABLE X

Gross and Derivative Values for Subject EB
at 30 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.28	0.	0.	0.30	0.	0.	0.34	0.	0.	0.34	0.
1	0.64	0.86	0.72	0.84	1.47	0.99	2.12	2.23	1.20	2.06	2.19	1.08
2	1.71	1.71	0.67	2.93	2.27	0.72	4.46	2.73	0.48	4.37	2.50	0.31
3	4.06	2.19	0.59	5.39	2.90	0.37	7.59	3.18	0.22	7.06	2.81	0.16
4	6.09	2.89	0.59	8.74	3.02	-0.19	10.83	3.18	0.08	10.00	2.81	-0.16
5	9.83	3.37	0.24	11.43	2.51	-0.25	13.95	3.35	0.17	12.69	2.50	-0.22
6	12.83	3.37	0.35	13.77	2.51	0.03	17.52	3.52	0.50	15.00	2.37	-0.03
7	16.57	4.06	0.83	16.48	2.57	-0.03	20.98	4.35	0.67	17.43	2.44	-0.13
8	20.95	5.02	0.75	18.91	2.45	-0.09	26.23	4.85	0.11	19.87	2.12	-0.16
9	26.61	5.56	-0.24	21.37	2.39	-0.03	30.69	4.58	-0.56	21.68	2.12	0.09
10	32.06	4.54	-1.28	23.70	2.39	-0.09	35.38	3.74	-1.09	24.12	2.31	-0.20
11	35.10	2.99	-1.39	26.16	2.21	-0.49	38.17	2.40	-1.01	26.31	1.72	-0.66
12	38.05	1.76	-0.99	28.13	1.41	-0.66	40.17	1.73	-0.50	27.56	1.00	-0.45
13	39.22	1.01	-0.45	28.97	0.90	-0.55	41.62	1.39	-0.33	28.31	0.81	-0.15
14	40.08	0.86	-0.16	29.93	0.30	0.	42.96	1.06	-0.33	29.18	0.70	-9.16
15	40.93	0.69	-0.09				43.74	0.73	-0.22	29.70	0.50	-0.12
16	41.47	0.68	0.06				44.41	0.61	-0.08	30.18	0.46	-0.04
17	42.30	0.81	0.04				44.97	0.56	-0.03	30.63	0.43	-0.04
18	43.08	0.76	-0.04				45.53	0.56	0.01	31.04	0.39	-0.04
19	43.82	0.73	-0.04				46.09	0.57	0.01	31.41	0.35	-0.04
20	44.54	0.68	-0.07				46.67	0.57	-0.01	31.74	0.32	-0.04
21	45.18	0.60	-0.08				47.23	0.55	-0.03	32.04	0.28	-0.04
22	45.74	0.52	-0.08				47.76	0.52	-0.03	32.30	0.24	-0.04
23	46.21	0.43	-0.08				48.27	0.50	-0.03	32.53	0.21	-0.04
24	46.60	0.35	-0.08				48.75	0.47	-0.09	32.72	0.17	0.07
25	46.91	0.28	0.				49.21	0.34	-0.08	32.87	0.34	0.

<u>TABLE XI</u>

Gross and Derivative Values for Subject SB
at 30 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.27	0.	0.	0.27	0.	0.	0.29	0.	0.	0.29	0.
1	1.07	1.12	0.53	1.08	1.47	0.85	2.35	2.46	1.14	2.19	2.38	1.04
2	2.25	1.34	0.72	2.93	1.98	0.54	4.92	2.57	0.33	4.75	2.38	-0.
3	3.74	2.57	1.10	5.03	2.54	0.40	7.49	3.13	0.47	6.94	2.38	0.16
4	7.38	3.53	0.61	8.02	2.78	0.24	11.17	3.52	0.22	9.51	2.69	0.19
5	10.80	3.79	0.78	10.60	3.02	0.09	14.52	3.57	0.17	12.32	2.75	-0.00
6	14.96	5.08	1.20	14.07	2.96	-0.31	18.32	3.85	0.47	15.01	2.69	0.00
7	20.95	6.20	0.19	16.52	2.40	-0.09	22.22	4.52	0.47	17.70	2.75	-0.06
8	27.36	5.45	-1.12	18.86	2.78	0.22	27.36	4.80	0.06	20.51	2.56	0.05
9	31.85	3.95	-1.12	22.09	2.84	-0.16	31.82	4.63	-0.56	22.83	2.85	-0.02
10	35.27	3.21	-0.67	24.55	2.46	-0.25	36.63	3.69	-0.95	26.20	2.53	-0.61
11	38.26	2.62	-0.75	27.00	2.34	-0.49	39.20	2.74	-0.76	27.89	1.68	-0.66
12	40.51	1.71	-0.78	29.22	1.47	-0.78	42.10	2.18	-0.75	29.45	1.22	-0.38
13	41.68	1.07	-0.48	29.93	0.78	-0.42	43.55	1.23	-0.61	30.32	0.88	-0.25
14	42.65	0.75	-0.24	30.77	0.63	-0.18	44.55	0.95	-0.20	31.20	0.72	-0.16
15	43.18	0.59	-0.04	31.20	0.41	-0.12	45.45	0.84	-0.12	31.77	0.56	-0.07
16	43.82	0.66	0.04	31.61	0.40	-0.02	46.23	0.72	-0.10	32.33	0.58	-0.00
17	44.50	0.68	0.01	32.00	0.38	-0.02	46.89	0.65	-0.05	32.93	0.56	-0.04
18	45.17	0.68	-0.01	32.37	0.36	-0.02	47.52	0.62	-0.04	33.46	0.49	-0.07
19	45.85	0.65	-0.01	32.72	0.34	-0.02	48.13	0.57	-0.04	33.91	0.42	-0.07
20	46.47	0.65	0.03	33.05	0.32	-0.02	48.65	0.54	0.01	34.30	0.35	-0.07
21	47.14	0.71	0.06	33.37	0.30	-0.02	49.21	0.58	0.04	34.61	0.28	-0.07
22	47.88	0.77	0.06	33.66	0.28	-0.02	49.81	0.61	0.04	34.85	0.21	-0.07
23	48.68	0.83	0.06	33.93	0.26	-0.02	50.44	0.65	0.04	35.10	0.13	-0.07
24	49.53	0.89	-0.28	34.19	0.25	0.00	51.11	0.69	-0.18	35.12	0.06	0.08
25	50.45	0.27	0.	34.42	0.27	0.	51.81	0.29	0.	35.14	0.29	0.

TABLE XII

Gross and Derivative Values for Subject HL
at 30 steps per min

Time	Normal Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	Hyperventilated Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.31	0.	0.	0.36	0.	0.	0.30	0.	0.	0.36	0.
1	0.89	1.17	0.85	1.00	1.53	0.82	2.46	2.80	1.41	2.32	2.25	0.98
2	2.34	2.01	0.45	3.06	2.00	0.23	5.59	3.13	0.20	4.50	2.32	0.06
3	4.90	2.06	0.45	4.99	2.00	0.25	8.72	3.19	0.00	6.95	2.38	-0.
4	6.46	2.90	0.84	7.05	2.49	0.34	11.97	3.13	-0.14	9.27	2.32	-0.
5	10.70	3.73	0.25	9.98	2.68	-0.09	14.99	2.91	-0.03	11.59	2.38	-0.03
6	13.93	4.50	0.19	12.41	2.31	-0.12	17.78	3.07	0.56	14.03	2.25	0.06
7	17.49	4.12	0.64	14.59	2.43	-0.06	21.13	4.03	0.75	16.09	2.50	0.16
8	22.16	4.68	0.11	17.27	2.18	-0.25	25.83	4.58	0.19	19.04	2.57	-0.16
9	26.84	4.34	-0.58	18.96	1.93	-0.16	30.30	4.41	-0.39	21.23	2.19	-0.22
10	30.85	3.51	-0.67	21.14	1.87	-0.09	34.66	3.80	-0.95	23.42	2.13	-0.27
11	33.85	3.01	-0.58	22.70	1.75	-0.14	37.90	2.52	-1.12	25.49	1.64	-0.47
12	36.86	2.34	-0.81	24.63	1.59	-0.41	39.70	1.57	-0.76	26.74	1.19	-0.33
13	38.53	1.39	-0.67	25.88	0.94	-0.53	41.04	1.01	-0.41	27.87	1.00	-0.26
14	39.64	1.00	-0.31	26.50	0.54	-0.25	41.71	0.73	-0.05	28.74	0.67	-0.28
15	40.54	0.78	-0.21	26.96	0.44	-0.07	42.49	0.90	-0.01	29.10	0.41	-0.13
16	41.20	0.59	-0.14	27.37	0.40	-0.04	43.50	0.71	-0.24	29.62	0.41	-0.03
17	41.71	0.49	-0.06	27.75	0.36	-0.04	43.92	0.41	-0.16	30.01	0.38	-0.03
18	42.19	0.47	-0.03	28.08	0.32	-0.04	44.33	0.40	-0.03	30.37	0.35	-0.03
19	42.65	0.44	-0.02	28.38	0.28	-0.04	44.72	0.36	-0.02	30.71	0.32	-0.03
20	43.08	0.42	-0.02	28.63	0.23	-0.04	45.05	0.35	0.02	31.01	0.29	-0.03
21	43.49	0.40	-0.02	28.85	0.19	-0.04	45.42	0.40	0.05	31.28	0.26	-0.03
22	43.87	0.37	-0.02	29.02	0.15	-0.04	45.84	0.45	0.05	31.52	0.23	-0.03
23	44.23	0.35	-0.02	29.16	0.11	-0.04	46.32	0.50	0.05	31.73	0.10	-0.03
24	44.56	0.32	-0.01	29.25	0.07	0.12	46.84	0.55	-0.10	31.91	0.16	0.08
25	44.88	0.31	0.	29.31	0.36	0.	47.41	0.30	0.	32.06	0.36	0.

TABLE XIII

Gross and Derivative Values for Subject EB
at 36 steps per min

Time	Normal Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	Hyperventilated Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.40	0.	0.	0.36	0.	0.	0.43	0.	0.	0.37	0.
1	0.89	1.61	1.16	1.24	1.58	1.00	1.55	2.32	1.33	2.41	2.35	1.25
2	3.21	2.71	0.91	3.16	2.36	0.77	4.64	3.09	0.58	4.70	2.88	0.42
3	6.31	3.43	0.69	5.95	3.13	0.53	7.73	3.48	0.36	8.16	3.18	0.22
4	10.07	4.09	0.42	9.42	3.41	-0.06	11.60	3.81	0.14	11.07	3.31	0.20
5	14.50	4.26	0.00	12.77	3.11	-0.17	15.35	3.75	0.14	14.78	3.59	-0.06
6	18.59	4.10	0.28	15.43	3.07	0.20	19.10	4.08	0.86	18.24	3.18	-0.40
7	22.69	4.82	0.41	18.90	3.41	-0.06	23.52	5.47	0.75	21.15	2.78	-0.29
8	28.22	4.92	-0.00	22.25	2.94	-0.43	30.04	5.58	-0.50	23.81	2.60	-0.03
9	32.54	4.81	-0.14	24.79	2.54	-0.29	34.67	4.47	-0.97	26.34	2.72	-0.06
10	37.85	4.65	-0.83	27.33	2.36	-0.19	38.98	3.64	-1.10	29.25	2.47	-0.40
11	41.83	3.15	-1.27	29.50	2.17	-0.42	41.96	2.26	-1.05	31.29	1.92	-0.51
12	44.16	2.10	-0.77	31.67	1.52	-0.68	43.50	1.55	-0.44	33.08	1.45	-0.49
13	46.04	1.61	-0.47	32.53	0.81	-0.44	45.05	1.38	-0.28	34.10	0.93	-0.45
14	47.37	1.16	-0.28	33.28	0.63	-0.16	46.26	0.99	-0.28	34.94	0.56	-0.28
15	48.36	1.05	-0.06	33.80	0.50	-0.09	47.04	0.83	-0.04	35.31	0.37	-0.10
16	49.47	1.04	-0.08	34.27	0.45	-0.04	47.92	0.91	0.02	35.68	0.36	-0.01
17	50.44	0190	-0.14	34.70	0.41	-0.04	48.85	0.87	-0.08	36.03	0.35	-0.01
18	51.28	0.76	-0.14	35.09	0.36	-0.04	49.66	0.75	-1.16	36.38	0.34	-0.01
19	51.97	0.63	-0.14	35.43	0.32	-0.04	50.35	0.55	-0.16	36.71	0.33	-0.01
20	52.53	0.49	-0.14	35.73	0.28	-0.04	50.75	0.42	-0.04	37.03	0.31	-0.01
21	52.94	0.35	-0.14	35.98	0.23	-0.04	51.19	0.46	0.04	37.34	0.30	-0.01
22	53.22	0.21	-0.14	36.19	0.19	-0.04	51.67	0.50	0.04	37.64	0.29	-0.01
23	53.37	0.07	-0.14	36.36	0.15	-0.04	52.19	0.53	0.04	37.92	0.28	-0.01
24	53.37	-0.07	0.16	36.48	0.10	0.11	52.74	0.57	-0.05	38.10	0.27	0.04
25	53.23	0.40	0.	36.56	0.36	0.	53.33	0.43	0.	38.46	0.37	0.

TABLE XIV

Gross and Derivative Values for Subject SB
at 36 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.30	0.	0.	0.34	0.	0.	0.33	0.	0.	0.33	0.
1	1.22	2.10	1.51	0.87	1.65	1.04	1.74	2.18	1.38	1.77	2.19	1.31
2	4.21	3.33	0.94	3.29	2.42	0.39	4.36	3.10	0.73	4.39	2.96	0.41
3	7.87	3.99	0.58	5.72	2.42	0.20	7.95	3.64	0.38	7.68	3.01	0.00
4	12.10	4.49	0.44	8.14	2.83	0.56	11.65	3.86	0.82	10.42	2.96	-0.06
5	16.86	4.88	0.47	11.37	3.54	0.42	15.67	5.28	0.82	13.59	2.89	-0.03
6	21.96	5.44	0.14	15.22	3.67	0.06	22.20	5.49	-0.35	16.21	2.89	0.06
7	27.73	5.16	-0.53	18.70	3.67	-0.26	26.66	4.57	-0.54	19.38	3.01	-0.05
8	32.28	4.38	-1.14	22.55	3.14	-0.75	31.34	4.41	-0.73	22.24	2.80	-0.23
9	36.50	2.87	-1.19	24.98	2.17	-0.73	35.48	3.10	-1.33	24.98	2.56	-0.53
10	38.03	2.00	-0.54	26.90	1.68	-0.57	37.54	1.74	-0.95	27.36	1.74	-0.76
11	40.49	1.79	-0.58	28.33	1.03	-0.53	39.96	1.10	-0.43	28.46	1.04	-0.50
12	41.60	0.83	-0.67	28.95	0.62	-0.23	39.94	0.87	-0.19	29.43	0.73	-0.27
13	42.16	0.44	-0.23	29.57	0.56	-0.07	40.70	0.82	-0.01	29.92	0.49	-0.15
14	42.49	0.37	-0.02	30.07	0.48	-0.06	41.57	0.86	-0.02	30.41	0.43	-0.06
15	42.90	0.41	0.02	30.52	0.43	-0.04	42.41	0.79	-0.10	30.79	0.37	-0.05
16	43.30	0.41	0.01	30.94	0.39	-0.04	43.14	0.67	-0.15	31.14	0.34	-0.02
17	43.71	0.42	0.01	31.31	0.35	-0.04	43.74	0.48	-0.15	31.47	0.32	-0.02
18	44.14	0.42	-0.01	31.63	0.31	-0.04	44.11	0.36	-0.06	31.78	0.30	-0.02
19	44.55	0.39	-0.02	31.92	0.26	-0.04	44.48	0.36	0.00	32.06	0.27	-0.02
20	44.93	0.37	-0.02	32.16	0.22	-0.04	44.84	0.36	-0.00	32.32	0.25	-0.02
21	45.29	0.35	-0.02	32.36	0.18	-0.04	45.20	0.36	-0.	32.56	0.23	-0.02
22	45.62	0.32	-0.02	32.52	0.14	-0.04	45.57	0.36	-0.01	32.77	0.20	-0.02
23	45.93	0.30	0.	32.64	0.09	-0.04	45.93	0.34	0.	32.96	0.18	-0.02

TABLE XV

Gross and Derivative Values for Subject HL
at 36 steps per min

Time	Normal Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	Hyperventilated Breathing VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.24	0.	0.	0.36	0.	0.	0.28	0.	0.	0.36	0.
1	0.78	1.40	1.03	1.94	2.06	1.10	1.43	2.31	1.54	2.53	2.34	1.41
2	2.79	2.29	0.98	4.13	2.56	0.55	4.62	3.36	0.58	4.68	3.18	0.71
3	5.36	3.35	1.01	7.07	3.16	0.44	8.14	3.47	0.14	8.88	3.76	-0.03
4	9.50	4.30	0.28	10.45	3.44	-0.09	11.56	3.63	0.19	12.21	3.11	-0.46
5	13.96	3.91	-0.20	13.95	2.97	-0.20	15.41	3.85	0.05	15.10	2.83	-0.14
6	17.32	3.91	0.56	16.39	3.03	0.13	19.26	3.74	0.22	17.87	2.83	-0.
7	21.78	5.03	0.64	20.02	3.22	-0.08	22.89	4.29	0.17	20.77	2.83	-0.09
8	27.37	5.20	-0.22	22.83	2.88	-0.23	27.84	4.07	-0.47	23.54	2.65	-0.25
9	32.17	4.58	-0.64	25.77	2.75	-0.38	31.03	3.36	-0.63	26.07	2.34	-0.31
10	36.52	3.91	-0.81	28.34	2.13	-0.67	34.55	2.80	-0.49	28.23	2.03	-0.39
11	39.99	2.96	-1.17	30.03	1.41	-0.59	36.64	2.37	-0.19	30.14	1.57	-0.23
12	42.45	1.56	-1.12	31.15	0.94	-0.30	39.28	2.42	-0.33	31.37	1.57	-0.03
13	43.12	0.73	-0.36	31.90	0.81	-0.14	41.48	1.70	-0.66	33.28	1.51	-0.38
14	43.90	0.84	0.08	32.78	0.66	-0.19	42.69	1.10	-0.41	34.39	0.81	-0.51
15	44.79	0.89	0.03	33.23	0.44	-0.13	43.68	0.88	-0.21	34.89	0.49	-0.16
16	45.69	0.89	-0.03	33.65	0.41	-0.03	44.45	0.67	-0.15	35.37	0.48	-0.02
17	46.58	0.84	-0.08	34.05	0.39	-0.03	45.03	0.58	-0.04	35.84	0.46	-0.02
18	47.36	0.73	-0.12	34.43	0.36	-0.03	45.62	0.59	0.03	36.29	0.44	-0.02
19	48.03	0.59	-0.12	34.78	0.34	-0.03	46.22	0.64	0.03	36.72	0.42	-0.02
20	48.54	0.48	-0.09	35.10	0.31	-0.03	46.89	0.65	-0.02	37.14	0.41	-0.02
21	48.99	0.43	-0.06	35.40	0.29	-0.03	47.51	0.60	-0.05	37.53	0.39	-0.02
22	49.37	0.35	-0.06	35.67	0.26	-0.03	48.09	0.55	-0.05	37.91	0.37	-0.02
23	49.69	0.29	-0.06	35.92	0.24	-0.03	48.61	0.50	-0.05	38.27	0.35	-0.02
24	49.95	0.23	-0.03	36.15	0.21	0.06	49.09	0.45	-0.11	38.62	0.34	0.00
25	50.15	0.24	0.	36.34	0.36	0.	49.52	0.28	0.	38.95	0.36	0.

TABLE XVI

Gross and Derivative Values for Subject EB
at 40 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.37	0.	0.	0.31	0.	0.	0.38	0.	0.	0.31	0.
1	1.22	1.72	1.26	1.00	1.21	0.84	2.00	2.50	1.62	1.43	1.87	1.35
2	3.44	2.89	1.08	2.43	1.99	0.76	5.00	3.61	1.34	3.74	3.02	0.67
3	7.00	3.89	0.97	4.98	2.74	0.64	9.22	5.17	0.67	7.47	3.21	0.09
4	11.22	4.84	0.94	7.91	3.27	0.44	15.34	4.95	-0.53	10.15	3.21	0.23
5	16.67	5.78	-0.08	11.52	3.61	0.05	19.11	4.11	-0.58	13.88	3.67	-0.12
6	22.78	4.67	-1.61	15.13	3.36	-0.51	23.56	3.78	-0.61	17.49	2.96	-0.71
7	26.00	2.56	-1.56	18.24	2.58	-0.81	26.67	2.89	-0.78	19.79	2.24	-0.48
8	27.90	1.56	-0.64	20.29	1.74	-0.73	29.34	2.23	-0.70	21.97	1.99	-0.42
9	29.12	1.28	-0.22	21.72	1.12	-0.48	31.12	1.50	-0.56	23.78	1.40	-0.53
10	30.45	1.11	-0.19	22.53	0.78	-0.19	32.34	1.11	-0.23	24.77	0.92	-0.31
11	31.34	0.89	-0.17	23.28	0.73	-0.05	33.34	1.00	-0.08	25.62	0.78	-0.16
12	32.23	0.78	-0.11	23.98	0.68	-0.05	34.34	0.95	-0.08	26.33	0.61	-0.14
13	32.89	0.67	-0.07	24.64	0.63	-0.05	35.23	0.83	-0.08	26.84	0.50	-0.07
14	33.56	0.64	-0.03	25.25	0.58	-0.05	36.01	0.78	-0.04	27.32	0.47	-0.03
15	34.18	0.60	-0.04	25.81	0.54	-0.05	36.79	0.75	-0.04	27.78	0.45	-0.03
16	34.77	0.56	-0.04	26.32	0.49	-0.05	37.51	0.69	-0.06	28.22	0.42	-0.03
17	35.31	0.52	-0.04	26.79	0.44	-0.05	38.17	0.63	-0.06	28.62	0.40	-0.03
18	35.80	0.48	-0.04	27.20	0.39	-0.05	38.78	0.57	-0.06	29.01	0.37	-0.03
19	36.26	0.43	-0.05	27.57	0.34	-0.04	39.32	0.52	-0.06	29.36	0.34	-0.03
20	36.67	0.37	0.	27.89	0.31	0.	39.81	0.46	-0.07	29.69	0.32	-0.02
21							40.24	0.38	0.	30.00	0.31	0.

TABLE XVII

Gross and Derivative Values for Subject HL
at 40 steps per min

Time	Normal Breathing						Hyperventilated Breathing					
	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$	VO_2	$\dot{V}O_2$	$\ddot{V}O_2$	VCO_2	$\dot{V}CO_2$	$\ddot{V}CO_2$
0	0.	0.31	0.	0.	0.35	0.	0.	0.33	0.	0.	0.35	0.
1	1.56	2.17	1.68	0.87	1.15	0.67	1.56	2.00	1.64	1.68	1.87	0.92
2	4.34	3.67	1.06	2.31	1.68	0.39	4.01	3.62	1.20	3.74	2.18	0.51
3	8.90	4.29	0.45	4.24	1.93	0.67	8.80	4.40	0.22	6.05	2.90	0.62
4	12.91	4.56	0.10	6.17	3.02	1.03	12.81	4.07	-0.28	9.54	3.43	0.12
5	18.03	4.68	-0.53	10.29	3.99	0.16	16.93	3.84	-0.50	12.91	3.15	-0.53
6	22.27	3.51	-1.20	14.15	3.34	-0.69	20.49	3.06	-0.72	15.84	2.37	-0.58
7	25.05	2.28	-0.97	16.96	2.62	-0.84	23.05	2.39	-0.61	17.65	2.00	-0.22
8	26.83	1.56	-0.58	19.39	1.65	-0.92	25.28	1.84	-0.56	19.83	1.93	-0.24
9	28.16	1.11	-0.36	20.27	0.78	-0.47	26.72	1.28	-0.42	21.51	1.51	-0.36
10	29.06	0.84	-0.14	20.95	0.72	0.02	27.84	1.00	-0.25	22.85	1.22	-0.29
11	29.84	0.84	-0.00	21.70	0.82	0.06	28.73	0.78	-0.20	23.94	0.92	-0.25
12	30.73	0.84	-0.03	22.59	0.84	-0.04	29.40	0.61	-0.14	24.70	0.72	-0.14
13	31.51	0.79	-0.05	23.38	0.74	-0.10	29.95	0.50	-0.08	25.38	0.64	-0.07
14	32.29	0.74	-0.06	24.07	0.64	-0.10	30.40	0.45	-0.02	25.98	0.57	-0.07
15	32.98	0.66	-0.07	24.66	0.54	-0.10	30.84	0.45	0.01	26.51	0.49	-0.07
16	33.60	0.58	-0.08	25.14	0.43	-0.10	31.30	0.46	0.01	26.97	0.42	-0.07
17	34.15	0.50	-0.08	25.53	0.33	-0.10	31.76	0.46	0.01	27.35	0.35	-0.07
18	34.61	0.42	-0.08	25.81	0.23	-0.10	32.23	0.47	0.01	27.66	0.27	-0.07
19	34.99	0.34	-0.05	25.99	0.13	0.06	32.70	0.48	-0.07	27.90	0.10	0.04
20	35.29	0.31	0.	26.06	0.35	0.	33.18	0.33	0.	28.06	0.35	0.