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# EVALUATION OF RESPIRATORY MEASURES FOR USE IN PILOT SELECTION

by

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and

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A report on a statistical analysis conducted by means of a grant-in-aid from the National Research Council Committee on Selection and Training of Aircraft Pilots from funds provided by the Civil Aeronautics Administration and the Works Progress Administration, upon data derived from research conducted at Pensacola, Florida, in cooperation with the United States Navy.

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Committee on Selection and Training of Aircraft Pilots

Executive Subcommittee

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NATIONAL RESEARCH COUNCIL

2101 Constitution Avenue, Washington, D. C.
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Committee on Selection and Training of Aircraft Pilots

January 17, 1944

Dr. Dean R. Brimhall
Director of Research
Civil Aeronautics Administration
Washington 25, D. C.

Dear Dr. Brimhall:

Attached is a report entitled Evaluation of Respiratory Measures for Use in Pilot Selection, by Raymond Franzen and Louisa Blaine. The report is submitted by the Committee on Selection and Training of Aircraft Pilots with the recommendation that it be included in the series of technical reports being issued by the Division of Research, Civil Aeronautics Administration.

The report is of particular interest because it embodies the results of a pioneering study of physiological variables frequently used in the examination of aircraft pilots, involving an exhaustive analysis of various measures for one variable, viz., metabolic respiration, with respect to reliability, interdependence, and association with flight success.

Cordially yours,

Morris S. Viteles, Chairman
Committee on Selection and
Training of Aircraft Pilots

MSV/es

## EDITORIAL FOREWORD

Approximately three years ago, the Committee on Selection and Training of Aircraft Pilots, in cooperation with the U. S. Navy, undertook a large scale research project using as subjects the Naval Aviation Cadets of the Naval Air Station, Pensacola, Florida. This project was undertaken for the purpose of evaluating certain predictors of achievement in flight training.

Among the variables investigated were those measures of physiological functions which were thought to have enough "clinical" validity to warrant their use as predictors of flight aptitude. With respect to these measures, as predictors of success or failure in flight training, the investigation yielded almost completely negative or inconclusive results.

The character of the findings suggested the need of a more intensive analysis of the variables in terms of reliability and interrelationships. This report presents the result of such a statistical analysis of one such complex variable, namely, respiration. Twenty-three measures obtainable from the breathing record are discussed and analyzed in the text.

## CONTENTS

## SUMMARY

Perhaps some of the most debated questions in the selection and training of aircraft pilots are those concerned with whether the physiological functions of the student pilot will predict his success in flight training. To what extent can flight aptitude be predicted from physiological measures? Can pilots who fail in flight training be differentiated from those who pass on the basis of their physiological functions? Is good pilot material being wasted simply for the reason that some applicants for flight training are rejected solely because they do not measure up to arbitrarily or authoritatively established medical standards? Such questions recur again and again in reports of pilot studies.

Most of the earlier studies were undertaken with the view to providing an answer to the second question. The physiological measures of flight failures were compared with the same measures for all pilots or with groups of successful pilots. Thus far, only negative or inconclusive findings have been forthcoming; failures cannot be differentiated on the basis of their medical records. However, these investigations have suffered from a lack of information concerning the physiological measures themselves. True, as they are now employed, these measures are of little value in the prediction of flight aptitude. But perhaps this is due to the fact that the measures themselves are at fault. They may be too unstable to be of any predictive value; they may be measuring the wrong aspects of the physical functions; etc.

Another, and perhaps more basic, attack on these questions is therefore needed. The measures themselves need to be investigated before they are used as predictors. Such an attack on the problem will perhaps reveal the most reliable or dependable measures of the physiological functions and perhaps isolate those functions which can be most accurately measured. This report presents the results of one such study concerned with an intensive statistical analysis of the breathing records of student pilots.

The graphic records of a pilot's breathing present an over-all picture of his respiratory pattern. From such records it is possible to score his respiratory behavior in 23 different ways. However, it is not to be assumed that all of these 23 scores are measuring a different aspect of breathing, nor is it proper to assume that all of these measures are equally dependable. Only a thorough going statistical analysis will provide the necessary information on these scores.

When these 23 measures were analysed statistically, it was found that only five of them were sufficiently reliable to justify their use in evaluating an individual's breathing behavior. Furthermore, it was demonstrated that the 18 discarded scores did not measure any aspect of the respiratory function that was not assessed by these five. The measures which were retained are: (1) Tidal Air Mean -- the average amount of air breathed during the inspiration-expiration cycle; (2) Tidal Air Sigma -- the variability in the amount of air breathed during the inspiration-expiration cycle; (3) Number of Cycles -- the number of inspiration-expiration cycles per minute; (4) Vital Capacity -- the

amount of air an individual can forcibly expire following a maximum inspiration; and (5) Oxygen Consumption -- the amount of air breathed per minute.

These five measures were then subjected to further statistical treatment to find out how they were interrelated. The question is whether they are completely independent aspects of respiration or whether certain of them cluster together as measures of the same aspect. It was found that three respiratory factors were necessary to account for the five measures. The first factor was composed primarily of the two Tidal Air measures; the second, is accounted for mainly by Vital Capacity; and the third factor is concerned with Oxygen Consumption. Number of Cycles is found in both the first and second factor, and the Tidal Air Sigma is slightly related to the first and third. These factors are supposedly different aspects of the respiratory function which are assessed by these measures.

After isolating reliable and independent measures of respiration, the problem of their relationship to success in flight training must again be attacked. Accordingly, the five respiratory measures of student pilots who failed in flight training were compared with those measures of the total group of pilots. Again, it was found that washouts could not be differentiated on the basis of these measures. The respiratory functions here measured have no direct association with flight aptitude.

It is pointed out that one of the reasons for this negative result might be the fact that too short a sample of the pilots' breathing behavior was studied. Complete faith cannot, therefore, be put in this negative conclusion until these same measures are secured over a longer period of time and analyzed again. It can be said, however, that the measures as they are now employed are of no predictive significance as far as success in flying is concerned.

## EVALUATION OF RESPIRATORY MEASURES FOR USE IN PILOT SELECTION

### INTRODUCTION

Experimental evaluation of the use of physiological measures in predicting adaptability to flying has been seriously handicapped by lack of information on the reliability of the measures themselves. A group of earlier studies[1] has attempted to investigate the predictive value of several of these physiological variables in terms of their ability to distinguich a group of flying cadets who failed in their flight training from a normal sample of pilots. Each of the measures studied seemed to have a good "clinical" basis for the hypothesis that pilot success would be associated with it. The upshot of these studies was that washouts could not be reliably distinguished from the total group of pilots on the basis of their scores on the physiological variables. This completely negative result might possibly be attributable to the failure to establish valid and reliable measures for the variables studied. Toward this end it was decided to subject the relevant data from these studies to an extensive statistical analysis with the view of providing further information on the reliability, independence, practicability, and significance of these physiological variables. It was hoped that such an analysis would reveal improved measures of the factors tested.

### PROBLEM

The present report is concerned with the statistical analysis of one of these variables, metabolic respiration. The respiratory records for two groups of Pensacola cadets included in previous studies were selected for analysis. One of these groups (Part I) was made up of 275 cases, the other (Part II), of 371. Each subject was subjected to two (nearly) consecutive 8-minute intervals of metabolic respiratory recordings. These records thus provide the source for a large number of measures of all aspects of the breathing pattern, each of which is available twice for each individual. They do not offer an opportunity to measure consistency over a long period of time. This phase of the evaluation must await other experimental definition. An analysis of these records does, however, provide the answers to the following questions:

1. What aspect of the breathing pattern should be measured and what kind of a measure should be used?

2. Is it desirable to use the entire 8-minute respiratory record of an individual or will a shorter time period be sufficient?

3. Which of the possible respiratory measures are the most reliable?

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[1] Statistical analyses of data obtained in the Pensacola study of Naval Aviators. Parts I and II. A final report on these studies is being prepared for publication in the near future.

4. Are any of the respiratory measures sufficiently reliable to warrant their use in differentiating individuals?

5. How many of the reliable measures represent independent functions?

6. How many factors are necessary to account for the reliable measures?

7. Is there any direct relationship between the reliable respiratory measures and success in flight training?

## RESPIRATORY RECORDS

Two consecutive 8-minute intervals of metabolic respiration were secured by means of a 9-liter Bendict-Roth closed-circuit spirometer. Each subject rested for at least 20 minutes after coming to the laboratory in the morning without breakfast. He was then given the mouthpiece and told to breathe in his usual manner.

In Figure 1 is presented a diagram of the record. The various parts of it may be explained as follows:

1. The <u>heavy</u> vertical lines demarcate 1-minute intervals. Half-minute intervals are shown by the <u>light</u> vertical lines.

2. The horizontal lines represent cubic centimeters. There are therefore 500 cc's. between the heavy lines. This is subdivided by the medium lines into five 100 cc. spaces. Each of these 100 cc. spaces is further divided into two 50 cc. units.

3. The breathing cycles are represented by the deflections between $e_1$-$i_1$-$e_2$, $e_2$-$i_2$-$e_3$, $e_3$-$i_3$-$e_4$, etc.

4. The inspirations are shown by $e_1$-$i_1$, $e_2$-$i_2$, and $e_3$-$i_3$. The labels $i_1$, $i_2$, and $i_3$ mark the furthest point of inspiration during each cycle.

5. Expirations are indicated by $i_1$-$e_2$, $i_2$-$e_3$, $i_3$-$e_4$, etc. The labels $e_1$, $e_2$, and $e_3$ mark the furthest point of expiration at each cycle.

6. Sighs are defined as "unusually" deep inspirations. These are denoted by "S" in Figure 1.

7. The midpoint of breathing, i.e., the line around which $e_1$, $e_2$, and $e_3$ vary is represented by the line AB. This is an arbitrary straight line fit of the expiration points.

8. $E_1I_1E_2I_2$ represents Vital Capacity. These two cycles, the deepest inspiration-expiration of which an individual is capable, twice repeated, are recorded separately from the rest of the test.

## RESPIRATORY MEASURES

From this record (Fig. 1) it was possible to isolate the following measures for statistical analysis:

1. Tidal Air (TA). The normal volume of air breathed in and out of the lungs with every quiet respiration, i.e., the volume of air breathed per inspiration-expiration cycle.

2. Duration of Cycles (Duration). The time elapsing between expirations.

3. The Absolute Variation of Inspiration Points (Inspir.). The depth of inspiration as it varies from an arbitrary midpoint of breathing.

4. Absolute Variation of Expiration Points (Expir.). The depth of expiration as it varies from an arbitrary midpoint of breathing.

5. Vital Capacity (VC). The number of cubic inches of air the individual can forcibly expire after as full an inspiration as possible.

6. Oxygen Consumption (OC). The amount of oxygen absorbed per minute.

7. Number of Cycles per minute (No. Cycles).

8. Regularity of Successive Cycles (Reg.). The average number of cycles which follow in succession above and below the arbitrary midpoint of breathing.

9. The Ratio of Tidal Air to Vital Capacity (TA/VC). The mean Tidal Air score divided by Vital Capacity.

10. The Ratio of Tidal Air (Mean) to Body Surface (TA/BS).

11. The Ratio of Oxygen Consumption to Minute Volume (OC/MV). The mean volume is the average amount of air breathed per minute instead of per cycle as in the Tidal Air measure.

12-23. It was decided to statistically test the Mean, Median, Average Deviation, and Standard Deviation of Tidal Air, Duration of Cycles, Absolute Variation of Inspiration Points, and Absolute Variation of Expiration Points, and to use as a measure of variability the Regularity of Succession of Cycles.

The records were measured with millimeter rulers except for the Duration of Cycles and the Oxygen Consumption which were determined respectively in seconds by means of a scale of seconds and in cubic centimeters. The methods for finding Number of Cycles and Regularity of Succession are described in the following pages. The ratios, of course, were found by simple division. Millimeters were converted into cubic centimeters by multiplying by a constant of 19.

The various measurements of the respiratory variables were obtained from the records in the following manner:

1. Tidal Air. The distance in mm. from $e_1$ to $i_1$ on a perpendicular from e constitutes the Tidal Air for a single cycle. The mean, median, average deviation, and standard deviation were calculated from the values $e_2$- $j_2$, $e_3$- $j_3$ (see Figure 2).

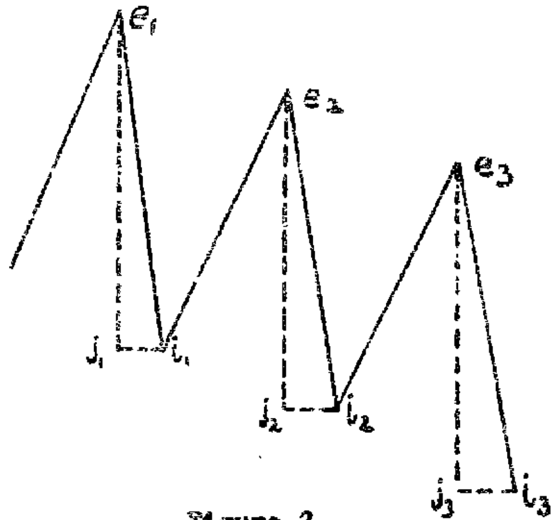


Figure 2
Determination of Tidal Air

These values were then corrected for temperature variation by multiplying the Tidal Air measure (also Minute Volume, Vital Capacity, and the Absolute Variation of Expiration and Inspiration) by the values given in Table I for a particular temperature.

TABLE I

CORRECTIONS FOR TEMPERATURE

| Temperature | Corrections |
|---|---|
| 18° C | 1.223 |
| 19° C | 1.219 |
| 20° C | 1.215 |
| 21° C | 1.210 |
| 22° C | 1.206 |
| 23° C | 1.202 |
| 24° C | 1.198 |
| 25° C | 1.194 |
| 26° C | 1.190 |
| 27° C | 1.186 |
| 28° C | 1.182 |
| 29° C | 1.178 |
| 30° C | 1.174 |
| 31° C | 1.170 |
| 32° C | 1.166 |
| 33° C | 1.162 |

2. Duration of Cycles. This is the distance in seconds between perpendiculars to the abscissa dropped from $e_1$, $e_2$, $e_3$ (see Figure 3).

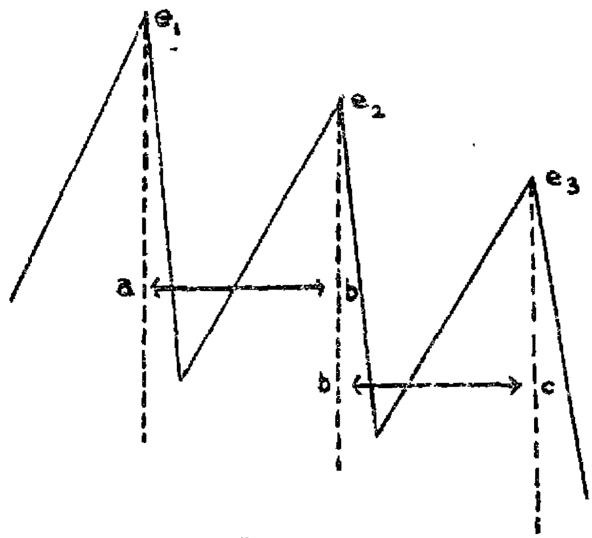


Figure 3
Determination of Duration of Cycles

The mean, median, average deviation, and standard deviation are found for the values a-b and b-c. Corrections for temperature are then made by referring to Table I.

3. Absolute Variation of Expiration Points. The line AB (Fig. 4) marks the midpoint of breathing from which the distance of each expiration point is measured in mm. along perpendiculars to the abscissa. The distances $e_1 - f_1$, $e_2 - f_2$, and $e_3 - f_3$ are treated irrespective of sign in computing the mean, median, average deviation, and standard deviation. Corrections for temperature (Table I) must then be made.

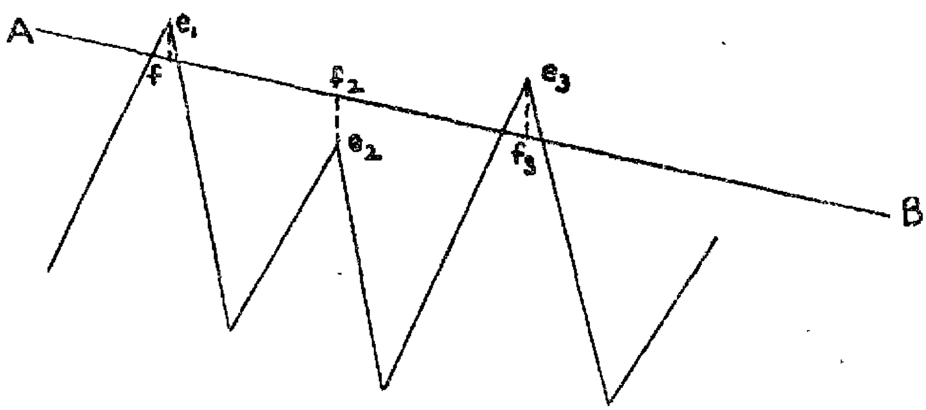


Figure 4
Determination of Absolute Variation of Expiration Points

4. Absolute Variation of Inspiration Points. The values used in this measurement are found, in the same manner as above, by finding the distances $i_1$-$j_1$, $i_2$- $j_2$, and $i_3$-$j_3$ (Fig. 5) and treating them irrespective of sign. The mean, median, average deviation, and standard deviation and the corrections for temperature (Table I) are computed as before.

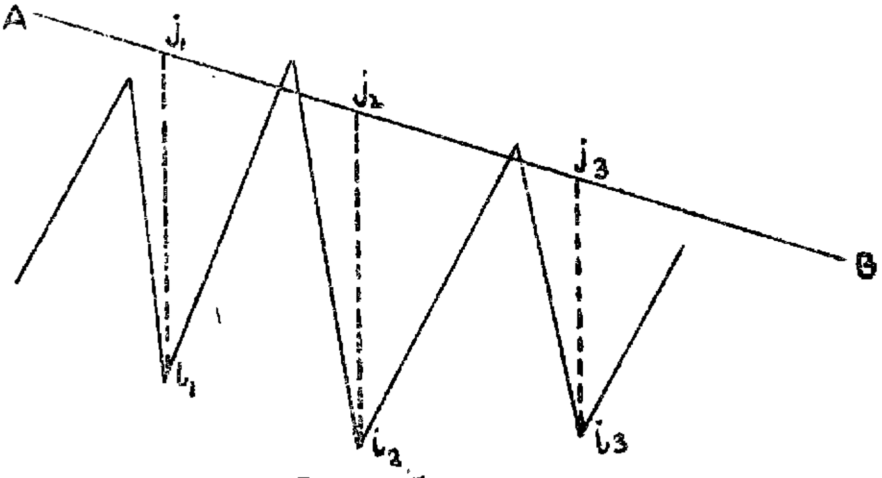


Figure 5
Determination of Absolute Variation of Inspiration Points

5. Vital Capacity. As mentioned above, the longer inspiration of the two cycles $E_1I_1E_2I_2$ shown in the lower part of Figure 1 is added to the longer expiration. As in computing the Tidal Air, the measurement is taken along perpendiculars from E and I. The correction for temperature in Table I is applied here also.

6. Oxygen Consumption. The vertical drop of line AB (Fig. 4) gives the Oxygen Consumption. It is found in cubic centimeters per minute by measuring the distance, CD, and dividing by the number of minutes. (See Fig. 1) Corrections for barometric pressure and temperature are made according to the tables in the Sanborn Company "Metabolism Tables."

7. Number of Cycles per Minute. The number of Expiration Points within the time interval employed are counted and divided by the number of minutes.

8. Regularity of Succession of Cycles. With line AB as a base, the number of Expiration Points above or below in succession are counted and divided

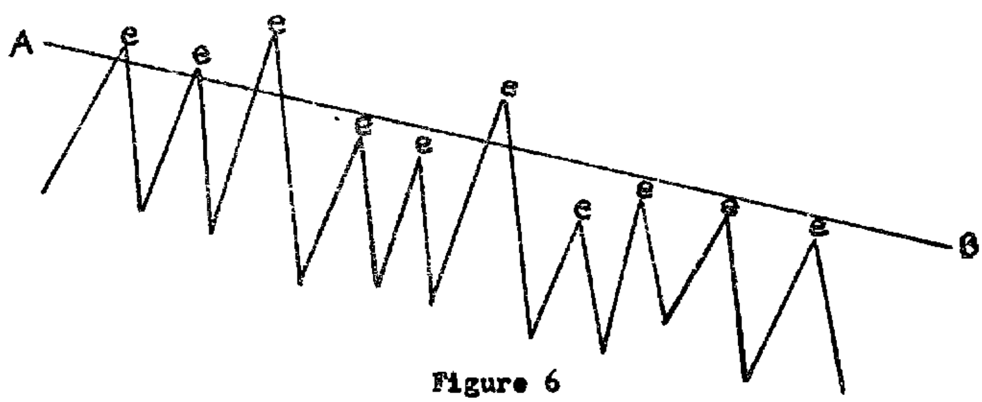


Figure 6
Regularity of Succession of Cycles

by the number of groupings. In Figure 6, for example, there are first 3 g's above, then 2 below, then 1 above, and 4 below. Thus, 3 + 2 + 1 + 4 ÷ 4 = 2.3, which is the measure for Regularity of Succession.

9-11. Ratios. The ratios of Tidal Air to Vital Capacity (TA/VC), Tidal Air to Body Surface (TA/BS), and Oxygen Consumption to Minute Volume (OC/MV) are self-explanatory. To find the Minute Volume, the total Tidal Air is divided by the number of minutes instead of by the number of cycles. The correction for temperature is, however, applied. Body Surface is found by means of the DuBois Body Surface Chart.

It will be noted that certain of the measures employed here possess basic similarities which must be taken into account in their interpretation.

Similarity of Tidal Air and Inspiration measures. Inspiration per Cycle is the same as the Tidal Air per cycle save for a small quantity in the latter occasioned by the distance of the Expiration Points from the arbitrary midline of breathing. This amount sometimes makes the Inspiration slightly more and sometimes slightly less than the Tidal Air, depending upon the position of the Expiration Points above or below the line. That is, the Tidal Air is always the distance between Expiration Points and their successive inspiration points along projected perpendiculars; the inspiration is always measured along a perpendicular from the inspiration points to the point where the perpendicular cuts the line (see Figure 7). Inspiration and Tidal Air therefore both measure <u>volume of air breathed</u>.

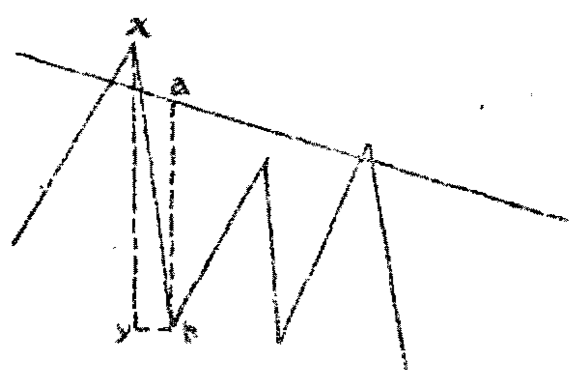


Figure 7
Similarity of Inspection (ab) on Tidal Air (xy)

Similarity of Duration and Number of Cycles. Duration and Number of Cycles are also the same, save for a small error of measurement, resulting from the fact that there is very seldom an even Number of Cycles within a two-minute span. However, it is evident that the rate of breathing can be measured equally well by determining the Duration per Cycle or simply counting the Number of Cycles per minute. If there are many cycles the Duration per Cycle will be small, and if there are few cycles it will be large, since the time is constant. Duration and Number of Cycles both measure in different ways the <u>rate of breathing</u>.

## RESULTS

### I. STATISTICAL ANALYSIS OF 25 PART I CASES TO SELECT RELIABLE VARIABLES

In order to select the length of record capable of yielding adequate measures and to select from among the total of 23, those variables best suited for further analysis (see the first 3 questions, page 1), 25 cases were chosen at random from the 275 cases of Part I of the previous studies[2] as an experimental group.

The first and last minutes of each of the eight minutes of record were eliminated and the remaining six minutes divided into three 2-minute intervals. It was important to see if it was necessary to measure a full six minutes or if one of the three smaller intervals would provide just as reliable measures. There were, therefore, three values for each factor on each of the two tests, except, of course, for Oxygen Consumption and Vital Capacity, since the former would be the same for each two minutes and only one test was available for the latter.

#### Reliability of Discarded Measures

Reliability was determined by correlating the results of each two minutes of the first test with the corresponding two minutes of the second test. The first elimination of variables was decided on the basis of this reliability. The measures found unsatisfactory on this basis are given in Table II.

TABLE II

TEN RESPIRATION VARIABLES DROPPED BECAUSE OF UNRELIABILITY
(N = 25)

| Variable | | Reliability Coefficients (Test-Retest) 1st 2 min. | 2nd 2 min. | 3rd 2 min. |
|---|---|---|---|---|
| Tidal Air: | Average Deviation | .54 | .73 | .39 |
| Duration: | Average Deviation | .39 | .55 | .26 |
| | Standard Deviation | .27 | .29 | -.11 |
| Expiration: | Mean | .25 | .47 | .32 |
| | Median | .26 | .33 | .49 |
| | Average Deviation | .08 | .20 | .13 |
| | Standard Deviation | .16 | .53 | .23 |
| Inspiration: | Average Deviation | .38 | .76 | .73 |
| | Standard Deviation | .31 | .77 | .59 |
| Regularity of Succession: | | .93 | .33 | .68 |

It must be noted that these are test-retest correlations with only a short lapse of time and do not represent reliability in the sense of true measures of

[2]See footnote 1, page 1.

distinction between organisms. They are tests of the reliability of individual distinctions at one time. There is good reason to believe that an important barrier to the physiological distinction of individuals lies in the relative size of the variance of a group at any one instant and of the variance of an individual over a period of time.

All of the other variables had reliability coefficients of .8 or better with the exception of the Tidal Air Sigma which was retained as the best measure available for regularity of breathing. Both the means and medians of the retained variables gave very satisfactory evidence of reliability but since it was obviously not necessary to use both it was decided to drop the medians. The means seemed slightly more reliable and are more convenient for mathematical treatment.

Reliability of Various Time Intervals of the Respiratory Records

Although measurements covering only two minutes yielded high enough reliabilities, there remained the question of which of the three two-minute intervals to use. To make this decision, the first two minutes of the first test were correlated with the second two minutes, the first with the third, and the second with the third. That interval which correlated most highly with the other two was taken to be the best, i.e., the most representative of the total six minutes.

TABLE III

INTERCORRELATIONS OF THREE TIME INTERVALS IN TEST 1 OF SOME OF THE RELIABLE RESPIRATION MEASURES[3]
(N = 25 Part I Cases)

| | 1st with 2nd 2 min. | 1st with 3rd 2 min. | 2nd with 3rd 2 min. |
|---|---|---|---|
| Tidal Air Mean | .93 | .85 | .93 |
| Tidal Air Sigma | .69 | .80 | .75 |
| Duration Mean | .97 | .92 | .94 |
| Inspiration Mean | .93 | .86 | .91 |
| Number of Cycles/min. | .95 | .90 | .94 |
| TA/BS | .90 | .85 | .90 |

On the basis of results of the foregoing analysis of 25 cases the following decisions were made:

1. To use the mean instead of the median.

[3]All retained variables are not included in this table. The necessary measures were not available for Vital Capacity and Oxygen Consumption. TA/VC and OC/MV are made up of variables otherwise included. Minute Volume is included as the numerator of Tidal Air Mean.

2. To retain no average or standard deviations except the sigma of Tidal Air.

3. To use the second two minutes since, in general, these are correlated most highly with the other two intervals.

It was also felt that the second test furnished better data than the first. It less often showed irregularities attributable to such influences as leaks in the apparatus and unnatural breathing. The second two minutes of the second test were used to obtain values for all variables except Number of Cycles. To obtain this measure the second two minutes of the first test were used for reasons that will be discussed later.

Reliability of the Retained Measures

The analysis of the 25 cases left eight measures (other than ratios) for further investigation. The reliability coefficients of these measures using 100 cases (selected at random from a total of 275 subjects) in Part I (including the 25 used in the preceding analysis), and 100 cases (selected at random from a total of 371 subjects) in Part II are presented in Tables IV and V.[4] The high reliability of the eight measures indicated by the experimental group of 25 cases is confirmed in these larger samples from both groups of subjects. The size of most of the coefficients in the three samples (25, 100, and 100) demonstrates that these selected variables may be used to distinguish individuals in respect to their respiration characteristics. Minute Volume and Tidal Air Sigma are not entirely satisfactory when both samples are considered. However, Minute Volume per Cycle (Tidal Air Mean) is satisfactory, and Tidal Air Sigma has been retained for further analyses because it is the only remaining measure of variability. The reliability of Oxygen Consumption is borderline.

TABLE IV

RELIABILITY COEFFICIENTS OF SELECTED RESPIRATION MEASURES OF SECOND TWO MINUTES OF SECOND TEST (N = 100 Part I Cases)

| Variable | N | $M_1$ | $M_2$ | $Sigma_1$ | $Sigma_2$ | r |
|---|---|---|---|---|---|---|
| Tidal Air Mean | 99 | 43.9 | 40.7 | 13.5 | 13.4 | .75 |
| Tidal Air Sigma | 92 | 6.7 | 6.9 | 3.9 | 3.9 | .76 |
| Duration Mean | 99 | 6.5 | 5.9 | 2.2 | 2.2 | .85 |
| Inspiration Mean | 99 | 43.4 | 39.7 | 13.3 | 13.8 | .77 |
| Number of Cycles | 100 | 9.9 | 10.2 | 3.2 | 3.3 | .84 |
| Vital Capacity | 99 | 274.0 | 277.0 | 32.0 | 33.0 | .89 |
| Oxygen Consumption | 100 | 284.0 | 272.0 | 56.0 | 45.0 | .70 |
| Minute Volume | 99 | 410.0 | 404.0 | 82.0 | 82.0 | .63 |

[4]Part I and Part II cases refer to the 275 and 371 subjects in these two Parts of earlier studies on Pensacola cadets. These identifications will be used throughout the rest of the paper. See footnote 1, page 1.

TABLE V

RELIABILITY COEFFICIENTS OF SELECTED RESPIRATION MEASURES
OF SECOND TWO MINUTES OF SECOND TEST[5]
(N = 100 Part II Cases)

| Variable | N | $M_1$ | $M_2$ | $Sigma_1$ | $Sigma_2$ | r |
|---|---|---|---|---|---|---|
| Tidal Air Mean | 100 | 50.5 | 47.5 | 14.5 | 15.7 | .87 |
| Tidal Air Sigma | 100 | 7.2 | 7.4 | 3.5 | 4.0 | .64 |
| Duration Mean | 100 | 6.3 | 6.0 | 2.1 | 1.8 | .85 |
| Inspiration Mean | 100 | 48.9 | 46.5 | 14.9 | 15.7 | .82 |
| Number of Cycles | 100 | 10.9 | 11.2 | 3.4 | 3.2 | .87 |
| Oxygen Consumption | 100 | 280.4 | 259.8 | 47.5 | 33.6 | .70 |
| Vital Capacity[6] | 100 | 276.0 | 273.0 | 36.0 | 34.0 | .87 |
| Minute Volume | 100 | 523.0 | 509.0 | 158.0 | 158.0 | .88 |

Since Duration of Cycles and Number of Cycles per Minute are reciprocals of each other except for errors of measurement (their eta is .92) both variables need not be used. Inasmuch as they are equally reliable it was decided to drop Duration because it is a more difficult measure to obtain and, therefore, more open to error.

The next step in the analysis was, therefore, to proceed with the analysis of these seven measures and their three ratios - Tidal Air/Vital Capacity, Tidal Air/Body Surface, and Oxygen Consumption/Minute Volume.

## II. ANALYSIS OF THE SEVEN SELECTED RESPIRATORY MEASURES AND THEIR RATIOS

It is essential now to investigate the independence or communality of these selected variables. The question raised in this connection is whether a separate aspect of breathing is covered by each of the measures or do some of them overlap in portraying a single characteristic? This question is, of course, answered by the presence or absence of intercorrelation among the variables.

### The Use of Ratios

Because of the way in which they are derived, it is not proper to correlate certain of the variables that are still being considered with each other. The three ratios cannot be correlated with either their numerator or denominator without introducing the spurious element of a chance error in one of the measures increasing the correlation because the chance distortion is embodied in both parties to the relationship. This spurious element is to be

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[5] The varying N's are accounted for by the fact that the 100 cases were selected at random and then exclusions were made for incomplete records.

[6] There is no test-retest of Vital Capacity as it is used in the intercorrelations since this measure is a combination of the longer expiration and longer inspiration of two attempts at a maximum cycle. The values in this table are a comparison of these two maximum cycles.

partially eliminated if the ratio is obtained from one test and the numerator or denominator (when treated separately) is obtained from another.

Even with the effect of chance errors removed in this fashion, great care still has to be exercised when including both of the component values in multiple relations. The mathematics of $r_{\frac{x}{y}y}$ or $r_{\frac{x}{y}x}$ shows that they are functions of the relationship of x and y and may, therefore, be without meaning over and above the direct relationship.[7] Although, under certain conditions, two of three simple variables, x, y, and their ratio may be used, the use of all three confounds the influence of the xy relationship. Justification for the use of one of the variables and the ratio instead of both variables yielding residuals is presented in Appendix I.

The ratios of Tidal Air to Body Surface (TA/BS) and to Vital Capacity (TA/VC) were suggested because they would approximate residuals of Tidal Air from regression predictions made by the controls (Body Surface or Vital Capacity). If the ratio does no better than the residual (depending upon the homoscedasticity) then the ratio can be eliminated as long as its terms are kept.

Strictly speaking, the Tidal Air Mean is a quotient, Minute Volume/Number of Cycles. Another problem arises in connection with both this measure and the Oxygen Consumption ratio. There is good reason to consider both of these ratios as physiological functions in their own right: one, the (average) size of respiratory cycle and the other, the utilization of the air breathed. It was in anticipation of the need to investigate both Tidal Air Mean and Number of Cycles that the latter measure, when treated alone, was obtained from the first test, whereas the numerator and denominator of Tidal Air were secured from the second set of measures. Thus any spurious element, due to common inclusion of chance error, is removed from the correlation of Tidal Air Mean with Number of Cycles,[8] and from Inspiration per Cycle with Number of Cycles. Since it seemed unlikely that both Tidal Air Mean and Minute Volume would be used it was decided to keep the latter measure from the second test but omit all the spurious correlations where Minute Volume enters into both variables.

## Intercorrelations

The matrix with the correlation coefficients omitted where the two variables contain common terms (i.e., where there is a possibility of spuriousness due to chance error in one variable which appears in both parties to the correlation) is given in Table VI. The first conclusion from these interrelations is that certain other of the variables may be eliminated.

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[7]See Appendix I for a discussion of the characteristics of $r_{\frac{x}{y}y}$.

[8]The correlation of Tidal Air Mean with Number of Cycles both taken from the second test is -.61 compared with -.52 given in Table VI. The difference represents the amount of correlation is spuriously raised by the presence of chance errors in Number of Cycles affecting both variables.

TABLE VI

r AND ETA OF EACH OF THE RESPIRATORY VARIABLES WITH EVERY OTHER[9]

(N = 275 Part I Cases)

| Respiratory Variable | Minute Volume r | eta | Tidal Air Mean r | eta | Inspir. per Cycle r | eta | TAM/VC r | eta | TAM/BS r | eta | Sigma TA r | eta | No. Cycles r | eta | VC r | eta | OC r | eta | OC/MV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minute Volume (MV) | | | | | | | | | | | | | | | | | | | |
| Tidal Air Mean (TAM) | -- | -- | | | | | | | | | | | | | | | | | |
| Inspir. per Cycle | .18 | .24 | .84 | .86 | | | | | | | | | | | | | | | |
| TAM/VC | -- | -- | -- | -- | .78 | .82 | | | | | | | | | | | | | |
| TAM/BS | -- | -- | -- | -- | .77 | .82 | -- | -- | | | | | | | | | | | |
| TA Sigma | .17 | .21 | .50 | .53 | .48 | .50 | .46 | .52 | .49 | .55 | | | | | | | | | |
| No. of Cycles (1) | .33 | .38 | -.52 | .66 | -.50 | .61 | -.44 | .60 | -.52 | .65 | -.38 | .42 | | | | | | | |
| Vital Capacity (VC) | .14 | .31 | .18 | .32 | .14 | .32 | -- | -- | .14 | .28 | .12 | .27 | -.15 | .30 | | | | | |
| $O_2$ Consumption (OC) | .13 | .31 | .06 | .21 | .07 | .25 | .06 | .20 | .04 | .16 | .14 | .21 | -.01 | .15 | .08 | .21 | | | |
| OC/MV | -- | -- | -- | -- | -.10 | .20 | -.10 | .21 | -.11 | .20 | -.05 | .21 | -.30 | .42 | -.06 | .21 | -- | -- | |
| Mean | 396.1 | | 41.0 | | 34.0 | | .2 | | 21.8 | | 7.7 | | 10.4 | | 279.8 | | 268.5 | | .7 |
| Sigma | 89.6 | | 15.5 | | 13.5 | | .1 | | 8.3 | | 4.4 | | 3.4 | | 34.4 | | 44.8 | | .2 |

[9]The etas are not discussed in the text because in no case does the difference between r and eta indicate non-linearity.

These two quotients then may offer possibilities as independent functions. However, before a quotient may be accepted in interrelations it must be demonstrated that the division of one variable by another is legitimate because it is implied by the nature of their co-variance. If not, then the relationships it exhibits will be nothing more than a compromise between the relationships exhibited by its two components. The combination of two variables in quotient form is warranted if the extent of variability of one around the regression is correlated with the other. If x and y are correlated and if the spread in the arrays of variable x increases or decreases proportionately with each increase of variable y, then x may be divided by y to obtain an expression of x, independent of y.[10] When these conditions are not met, dividing x by y when they are correlated, arbitrarily decreases the variability of the ratios at one end of the distribution of x. If x and y are not correlated, there is reason to combine them in any manner.

The Tidal Air Mean (the ratio of Minute Volume to Number of Cycles per Minute) meets the conditions which justify its use. The numerator and denominator are correlated .44 and .41 in the cases for Parts I and II cases respectively when both measures come from the same test. The variance of the numerator increases as the denominator increases. The Oxygen Consumption ratio does not meet these conditions. (See Table VII.)

TABLE VII

EVALUATION OF THE RATIOS OC/MV AND MV/NO. CYCLES

| Standard Deviation Interval | OC at Intervals of MV (Group I) | MV Intervals of No. of Cycles (Group II)[11] |
|---|---|---|
| 1.8 and above | .9 | 1.4 |
| 1.7 to 1.3 | .9 | 1.1 |
| 1.2 to 1.0 | 1.1 | 1.1 |
| .9 to .7 | 1.0 | .9 |
| .6 to .4 | .9 | .9 |
| .3 to .1 | 1.1 | 1.0 |
| 0 | 1.2 | .9 |
| -.1 to -.3 | 1.1 | .7 |
| -.4 to -.6 | 1.0 | .7 |
| -.7 to -.9 | .8 | .9 |
| -1.0 to -1.2 | 1.1 | .6 |
| -1.3 to -1.7 | 1.0 | 1.0 |
| -1.8 and less | | .5 |

[10]This is an analogous situation to the intelligence quotient. Mental age not only increases in average but also increases in spread with increases in chronological age.

[11]Although Group I cases were used this far, it was elected to use Part II cases for this study of the relation of Minute Volume and Number of Cycles because the former exhibited much larger variability in the second sample and would, therefore, more clearly represent the character of the relationship.

Since Inspiration per Cycle and Tidal Air Mean differ only slightly as measures of the average size of the cycle (their correlation in Part I is .84 and their reliabilities in Part I are lower than this), it is not necessary to use both. Tidal Air Mean was retained because it offered economy in computations if Tidal Air Sigma were to be used also.

## Semi-Partials, Multiples, and Residuals

The hypothesis of multiple relations involving Tidal Air Mean (i.e., Tidal Air Mean divided by Vital Capacity or by Body Surface) is negated when the r's of the two ratios are compared with those of their numerator. The r's of the ratios are very close to those of the Mean itself, and this would probably hold for relations with other variables as well as those in this study. They are slightly lower, which would indicate that the Tidal Air Mean (TAM) uncorrected is satisfactory in this type of sample. There is no way to estimate whether this would be true if better estimates of Body Surface were available. Even the use of residuals will not improve TAM uncorrected with the other variables in this study. This is evidenced by the semi-partial[12] and multiple correlations of the variables making up the ratios (see Table VIII).

TABLE VIII

SEMI-PARTIAL AND MULTIPLE CORRELATIONS OF VARIABLES MAKING UP THE RATIOS

| x<br>Variable | y<br>TAM | y<br>TAM/VC | y z<br>TAM VC | y z<br>TAM VC |
|---|---|---|---|---|
| | $r_{xy}$ | $r_{xy}$ | $r_{x(y.z)}$ | $R_{x.yz}$ |
| TA Sigma | .50 | .46 | .48 | .50 |
| No. of Cycles (1) | -.52 | -.44 | -.51 | .53 |
| Oxygen Consumption | .06 | .06 | .05 | .09 |

The two Tidal Air Mean ratios and the entire concept of improving the Tidal Air measure by combining with it or subtracting from it the influence of these other variables may therefore be eliminated.

The hypothesis of the independent function of the Oxygen Consumption ratio and Tidal Air Mean has already been explained. The correlation pattern of these quotients (Table VI) suggests confirmation of this hypothesis to the extent that their correlations differ from the corresponding correlations of their respective numerators. Thus, though the Oxygen ratio correlations are low, they exhibit differences from Oxygen Consumption as such in the change of sign and also in the .3 correlation with Number of Cycles. The Tidal Air Mean exhibits relations with Tidal Air Sigma and Number of Cycles significantly different from those of Minute Volume.

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[12] $r_{x(y.s)} = \frac{r_{xy} - r_{xs} r_{ys}}{k_{ys}}$ Raymond Franzen, A comment on partial correlation, *J. educ. Psychol.* 1928, 19, 194-197.

(The same conclusion may be drawn in respect to ratios of TAM to Body Surface but applies only to the imperfect estimates used in this study and to groups with anthropometric variance like this one.)

The evidence indicates that there is no justification for expressing Oxygen Consumption independent of Minute Volume as a ratio. In addition to the tendency for the spread of Oxygen Consumption to remain constant, regardless of values of Minute Volume these two are correlated only .13 in Part I cases and .26 in Part II cases.

The residuals of Oxygen Consumption from its regression on Minute Volume are empirically determined expressions of Oxygen Consumption when independent of Minute Volume. These correlate only .58 with the ratio. This function may still be investigated by means of these residuals.[13] The Oxygen Consumption residuals have correlations like those of total Oxygen Consumption. This, of course, follows from the low correlation between the two variables involved in the residual.

TABLE IX

CORRELATION OF OXYGEN CONSUMPTION RESIDUALS WITH OTHER VARIABLES

| Respiratory Variable | TAM | Inspiration | TA Sigma | No. of Cycles | VC |
|---|---|---|---|---|---|
| OC independent of MV | .08 | .08 | .10 | -.06 | .04 |
| OC | .06 | .07 | .14 | -.01 | .08 |
| OC/MV | -.11 | -.10 | -.05 | -.30 | -.06 |
| MV | -- | .18 | .17 | .33 | .14 |

Oxygen Consumption independent of Minute Volume is obviously a meaningless concept. The difference in correlation that the ratio seems to exhibit are entirely spurious. The ratio's correlations in Table IX merely reflect the correlations of Minute Volume reduced because of the chance error (r between MV + OC = .13--Table VI) introduced by making it the denominator of Oxygen Consumption. The signs are, of course, reversed.

Although the relation of Minute Volume to Number of Cycles justifies their use in quotient form, it is still not known that this quotient (average size of the cycle) is the best expression of Minute Volume, independent of Number of Cycles per Minute.

A comparison of the correlations of the quotient with the corresponding correlations using residuals,[14] throws some very interesting light on the use of a ratio (Table X).

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[13] For this purpose, the theoretical semi-partial $r_{x(y.z.)} = \frac{r_{xy} - r_{xz} \cdot r_{yz}}{k_{yz}}$ was not used. In order to avoid any error in such theoretical r's arising from lack of homoscedasticity, the actual residuals of Oxygen Consumption $\frac{X}{\sigma x} - (r_{xy} \frac{Y}{\sigma y})$ were computed and then correlated with the other variables.

[14] The r's were obtained from computed $\frac{X}{\sigma x}$ $r_{xy} \frac{Y}{\sigma y}$. They are not theoretical semi-partials. These values were computed for Part II cases since they have the greater spread in Minute Value.

TABLE X

COMPARISON OF r's OF THE QUOTIENT WITH CORRESPONDING r's USING RESIDUALS

| Respiratory Variables | TA Sigma | No. of Cycles (1) | VC | OC |
|---|---|---|---|---|
| MV independent of No. of Cycles | .37 | .01 | .17 | .30 |
| MV/No. of Cycles (TAM) | .54 | -.47 | .22 | .27 |

The similarity of the relations with Vital Capacity and Oxygen Consumption vindicates the quotient as a good practical expression of the Minute Volume partial, as does its own correlation with the residuals which is .75.

The correlation of -.47 (Table X) with Number of Cycles reaffirms the question of the significance of the correlation of a quotient with one of its members even when chance spurious error has been removed. The comparable residuals have a zero correlation.[15] It is demonstrated in Appendix I that such negatives are a statistical artifact of ratios. It leads to the conclusion that quotients should not be used together with their terms in multiple regression analysis. If they are used it must be with due recognition of the artifact.

If Tidal Air Mean was considered as a ratio, rather than as an average (since Number of Cycles is not an irrelevant value as are the N's of different sized groups) the fact that the self-correlation of Number of Cycles appearing in both the ratio (Mean) and the Sigma has raised their correlations with Number of Cycles would have to be accepted. All such questions might be avoided if the Minute Volume residuals were used. Residuals avoid the artifact that is present in the correlation of a ratio and one of its terms but they are very impracticable in any routine measurement of respiration. Inasmuch as the Tidal Air Mean has met the requirements for representing the residuals, it is safe to adopt it as the measure of breathing volume (with certain qualifications about its relations).

## III. ANALYSIS OF THE REMAINING FIVE RESPIRATORY MEASURES

The foregoing analysis has now reduced the significant and independent respiratory functions to 5 possible measures:

1. Tidal Air Mean (TAM).
2. Tidal Air Sigma (TASig.).
3. No. of Cycles (taken from another test).
4. Vital Capacity (VC).
5. Oxygen Consumption (OC).

They have been sifted from a set of 23 measures, the criteria of acceptance being first test-retest reliability, and second, independence of function, both physiologically and mathematically.

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[15] The theoretical semi-partial is truly zero. $r_y(x.y) = \frac{r_{xy} - r_{xy}\, r_{xy}}{k_{xy}}$

Since $r_{yy} = 1$, $r_y(x.y) = 0$. This, of course, implies that variable y and the y of x.y are the same, not taken from different sets of material.

## Intercorrelations

Before considering their interrelations as such, it is reassuring to note how closely the matrices for the two samples given in Table XI resemble each other. Except for two of the Oxygen Consumption correlations, the matrices are practically identical. (Oxygen Consumption together with Tidal Air Sigma exhibited the least satisfactory reliability of any of the selected variables). Such stability of relationship provides unmistakable evidence that the measures involved truly reflect physiological differences among individuals.

TABLE XI

INTERCORRELATION OF FIVE SELECTED RESPIRATORY VARIABLES

PART I CASES

(N = 275 for inter-r's: 100 for reliabilities)

| Respiratory Variable | TAM | TA Sig. | No. of Cycles[16] | OC | VC |
|---|---|---|---|---|---|
| Tidal Air Mean | (.75) | | | | |
| Tidal Air Sigma | .50 | (.76) | | | |
| No. of Cycles (1) | .53 | .38 | (.84) | | |
| Oxygen Consumption | .06 | .14 | .01 | (.70) | |
| Vital Capacity | .18 | .12 | .15 | .80 | (.89) |
| Mean | 41.0 | 7.7 | 10.4 | 268.5 | 279.8 |
| Sigma | 15.5 | 4.4 | 3.4 | 44.8 | 34.4 |

PART II CASES

(N = 371 for inter-r's: 100 for reliabilities)

| Variable | TAM | TA Sig. | No. of Cycles | OC | VC |
|---|---|---|---|---|---|
| Tidal Air Mean | (.87) | | | | |
| Tidal Air Sigma | .54 | (.64) | | | |
| No. of Cycles (1) | .47 | .35 | (.87) | | |
| Oxygen Consumption | .27 | .18 | -.01 | (.70) | |
| Vital Capacity | .22 | .10 | .12 | .28 | (.87) |
| Mean | 46.3 | 7.4 | 11.2 | 257.5 | 276.1 |
| Sigma | 15.4 | 4.1 | 3.2 | 31.8 | 34.9 |

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[16] Signs reversed for factor analysis.

It is obvious from inspection of these intercorrelations (Table XI) that there is a factor common to Tidal Air Mean, Tidal Air Sigma, and Number of Cycles. It is also probable, though not as clear, that Vital Capacity and Oxygen Consumption are independent, i.e., constitute discrete factors in themselves.

## Factor Analysis

A multiple factor analysis was carried out using the correlations from both Part I and Part II (Table XI). The rotated and unrotated factor loadings for the two matrices are presented in Table XII.

TABLE XII

FACTOR LOADINGS OF FIVE RESPIRATORY VARIABLES

UNROTATED

Factor

| Respiratory Variable | A | | B | | C | | $h^2$ | |
|---|---|---|---|---|---|---|---|---|
| (r) | Pt I | Pt II | Pt I | Pt II | Pt I | Pt II | Pt I | Pt II |
| 1. TAM | .70 | .79 | .36 | .29 | .06 | .21 | .62 | .76 |
| 2. TA Sig. | .66 | .60 | .28 | .31 | -.35 | .24 | .64 | .52 |
| 3. N of C (1) | .66 | .60 | .35 | .40 | .21 | -.36 | .61 | .65 |
| 4. OC | .35 | .47 | -.36 | -.44 | -.44 | .35 | .44 | .53 |
| 5. VC | .50 | .53 | -.39 | -.46 | .35 | -.32 | .52 | .59 |

AFTER ROTATION[17]

| Variable | A | | B | | C | | $h^2$ | |
|---|---|---|---|---|---|---|---|---|
| | Pt I | Pt II | Pt I | Pt II | Pt I | Pt II | Pt I | Pt II |
| 1. TAM | .76 | .75 | .22 | -.13 | .09 | .41 | .63 | .75 |
| 2. TA Sig. | .67 | .64 | .00 | .00 | .44 | .33 | .64 | .52 |
| 3. N of C (1) | .72 | .70 | .29 | .37 | .04 | -.14 | .61 | .65 |
| 4. OC | .00 | .00 | .14 | .22 | .65 | .70 | .44 | .53 |
| 5. VC | .09 | .02 | .71 | .73 | .10 | .26 | .52 | .59 |

The two Tidal Air Measures and Number of Cycles form a completely self-contained factor. Vital Capacity dominates another with Number of Cycles possibly contributing. The third factor is least precise with Oxygen Consumption the largest element, but with Tidal Air Mean involved in the Part II data and Tidal Air Sigma in Part I.

The degree of relationship to each factor of each of its determining variables is stated in Table XIII which gives the multiple correlation when all pertinent variables are included and also (by means of the semi-partials) the amount that each variable contributes to this multiple.

[17] Three rotations for Part II and 2 rotations for Part I were made.

Factor B is clearly seen to be mainly the function of Vital Capacity. Number of Cycles is the other element. R, including Number of Cycles, is increased over the zero order r with Vital Capacity alone, from .71 to .73 and from .73 to .78 in the two parts of the data.

Factor C is obviously mainly determined by Oxygen Consumption. Tidal Air Mean adds nothing in either part of the data since it raises the first order R's only .01. Tidal Air Sigma increases the relationship in Part I by .09, but only by .03 in Part II. It seems likely that the safest judgment would be to consider the factor as consisting of Oxygen Consumption with a small contribution from Tidal Air Sigma.

## IV. CORRELATION OF RESPIRATORY MEASURES WITH OTHER PSYCHO-PHYSIOLOGICAL VARIABLES

The statistical analyses undertaken thus far have isolated five respiratory variables that reliably distinguish among the respiratory characteristics of individuals. It is possible that as a battery the three respiratory factors will so distribute individuals that sections of the distribution might be considered as respiratory "types." Because of this possibility it seemed pertinent to study the relation of these measures to other batteries of tests that supposedly measure "type" differences. The following three tables (Tables XIV, XV, and XVI)[18] present the r's and eta's of each of the five respiratory measures with somatotype, Electro-encephalogram, and Tilt Table measures for the same individuals.[19]

The amazing thing about these manifolds is the total absence of relationship. All of the correlations are under .2, and only four of the eta's are as high as .3. Selected respiratory characteristics are uncorrelated with both Somatotype and E.E.G. (It has previously been shown that these two are themselves uncorrelated.) It may be considered that if they do measure "types" they measure three different kinds of types (Tables XIV and XV). The respiratory measures show no relation to thirteen cardiovascular measures recorded during the Tilt Table studies (Table XVI).

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[18]Inspiration appears in these tables instead of Tidal Air Mean. These correlations were obtained at the outset of the study. The respiratory variables were selected so as to be representative of different aspects of breathing. It was thought from the nature of the measure that Inspiration would best represent volume of air. It was not thought worth while to compute the correlations with Tidal Air Mean, first because the two are correlated over .8 with each other, and second, because of the completely negative result of these findings.

[19]The full description of these measures and the procedure by which they were secured will be presented in a subsequent report of the early Pensacola studies. (See footnote 1, page 1.) A description of the apparatus and procedures used in the electroencephalographic studies is also presented in Electroencephalography of Naval Aviators. Washington, D.C.: C.A.A. Division of Research, Report # 13, April 1943. A description of somatotyping procedures is presented in two volumes by W.H. Sheldon: (1) The Varieties of Human Physique, 1940 and (2) The Varieties of Temperament, 1942. New York, Harper & Bros.

TABLE XIV

CORRELATION OF FIVE RESPIRATORY MEASURES WITH SHELDON'S SOMATOTYPE FACTORS[20]
(N = 150 to 264)

PART I CASES

| Respiratory Variable | Somatotype 1 | | Somatotype 2 | | Somatotype 3 | | Dysplasia | |
|---|---|---|---|---|---|---|---|---|
| | r | eta | r | eta | r | eta | r | eta |
| Tidal Air Sigma | -.04 | .23 | -.02 | .08 | .05 | .18 | -.12 | .18 |
| Inspir./Cycle | -.07 | .22 | .03 | .09 | .05 | .16 | -.13 | .31 |
| Vital Capacity | -.13 | .15 | .08 | .16 | .13 | .22 | .01 | .21 |
| O2 Consumption | .14 | .25 | .15 | .23 | -.15 | .28 | .04 | .32 |
| No. of Cycles | .17 | .21 | -.07 | .16 | -.05 | .16 | .12 | .30 |

TABLE XV

CORRELATION OF FIVE RESPIRATORY MEASURES WITH ELECTROENCEPHALOGRAPH MEASURES
(N = 259

PART I CASES

| Respiratory Variable | Voltage | | Abnormalities | | Alpha Freq. | | Alpha (L + R) | |
|---|---|---|---|---|---|---|---|---|
| | r | eta | r | eta | r | eta | r | eta |
| Tidal Air Sigma | .05 | .28 | .002 | .18 | -.03 | .19 | .03 | .18 |
| Inspir./Cycle | -.03 | .23 | -.15 | .22 | .01 | .12 | .01 | .21 |
| Vital Capacity | .02 | .22 | .01 | .12 | .08 | .25 | -.001 | .20 |
| $O_2$ Consumption | .06 | .21 | -.03 | .15 | .01 | .23 | .04 | .22 |
| No. of Cycles | .05 | .15 | .07 | .17 | .02 | .26 | .01 | .23 |

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[20] Somatotypes 1, 2, and 3, refer to ratings for each cadet on three "componets" of body structure, described as "primary" aspects of body constitution. Somatotype 1, endomorphy, refers to dominance of visceral structure or soft roundness of body regions; somatotype 2, mesomorphy, indicates the athletic type of build or dominance of bone and muscle; and type 3, ectomorphy, indicates a dominance of "linearity" and "fragility," especially of the nervous system and sense organs. Dysplasia is a term used to signify "disharmony between different regions of the same physique." See Sheldon, W. H. op. cit.

TABLE XVI

CORRELATION OF FIVE RESPIRATORY MEASURES WITH THIRTEEN TILT TABLE VARIABLES
(N = 264)

PART I CASES

| Tilt Table Variables | Respiratory Variables: Tidal Air Sigma | | Inspir. Cycle | | Vital Capacity | | $O_2$ Consump. | | No. of Cycles | |
|---|---|---|---|---|---|---|---|---|---|---|
| | r | eta | r | eta | r | eta | r | eta | r | eta |
| Initial Systolic change | -.04 | .28 | .00 | .16 | .15 | .30 | .02 | .16 | .00 | .20 |
| Maximum Systolic change | .02 | .17 | .06 | .18 | .12 | .24 | .06 | .17 | .01 | .14 |
| Time to Maximum Systolic change | .04 | .27 | -.05 | .24 | .01 | .23 | .08 | .12 | -.03 | .18 |
| Initial Diastolic change | -.01 | .19 | -.02 | .22 | -.05 | .26 | -.02 | .21 | -.07 | .24 |
| Maximum Diastolic change | -.15 | .28 | -.09 | .21 | -.09 | .22 | .06 | .25 | .08 | .20 |
| Time to Maximum Diastolic change | -.06 | .17 | -.10 | .16 | -.06 | .17 | .06 | .20 | .09 | .21 |
| Initial Pulse Rate change | .09 | .17 | .09 | .19 | .08 | .27 | .07 | .29 | -.15 | .22 |
| Maximum Pulse Rate | -.02 | .23 | -.05 | .16 | .17 | .06 | .02 | .24 | .11 | .22 |
| Time to Maximum Pulse Rate | -.13 | .19 | -.04 | .15 | -.01 | .15 | -.05 | .25 | .08 | .23 |
| Pulse Pressure change | .16 | .27 | .00 | .24 | -.08 | .22 | .00 | .22 | -.05 | .21 |
| Pulse Rate change | .08 | .22 | .00 | .24 | -.11 | .17 | .00 | .18 | -.01 | .13 |
| Smallest Pulse Pressure | -.10 | .24 | .02 | .26 | .11 | .22 | .03 | .17 | .07 | .23 |
| Time Interval to Smallest P.P. | .06 | .21 | .07 | .24 | .07 | .26 | .04 | .11 | -.04 | .23 |

## V. THE PROBABILITY THAT WASHOUTS FOR APTITUDE ARE NOT SIGNIFICANTLY DIFFERENT FROM ALL PILOTS IN THEIR SCORES ON RESPIRATORY TESTS

These selected tests offer the possibility that respiratory characteristics bear a positive association with proficiency in flight training. To evaluate the tests in this respect the scores of pilots who have been washed out for inaptitude are compared with those of the total group of pilots. Since the number of washouts is not large it would increase the reliability of the findings if the two samples (Part I and Part II cases) could be combined. But before the combination is made it must be known that they are two random samples of the same universe so that their combination will yield homogeneous data.

It was found in the analysis of other physiological measures of these same two groups that for some reason the two sets of data were different enough not to meet the necessary requirement of homogeneity.[21] It is not surprising, therefore, that wide differences are found in the score distributions of the subjects in Part I and Part II as evidenced by the P's in Table XVII.

TABLE XVII

COMPARISON OF THE DISTRIBUTIONS OF PART I AND PART II CASES[22]

| Respiratory Variable | P | $X^2$ | Degrees of Freedom | Part I[23] N | Part I[23] M | Part I[23] Sigma | Part II N | Part II M | Part II Sigma |
|---|---|---|---|---|---|---|---|---|---|
| Tidal Air Mean | .01 | 19.4 | 8 | 300 | 41.0 | 15.5 | 371 | 46.3 | 15.4 |
| Tidal Air Sigma | .25 | 10.3 | 8 | 300 | 7.7 | 4.4 | 371 | 7.4 | 4.1 |
| No. of Cycles | .00 | 26.4 | 9 | 300 | 10.4 | 3.4 | 371 | 11.2 | 3.2 |
| OC Consumption | .01 | 21.7 | 8 | 282 | 268.0 | 55.0 | 371 | 257.0 | 32.0 |
| Vital Capacity | .58 | 7.5 | 9 | 294 | 280.0 | 34.0 | 371 | 276.0 | 35.0 |

On three of the measures the distributions fall below the .05 level of significant difference. Less than five times out of 100 would chance create differences as large or larger than those between the two distributions of

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[21] See footnote 1, page 1.

[22] $$X^2 = \frac{1}{N_1 N_2} \sum \frac{(f_1 N_2 - f_2 N_1)^2}{f_1 + f_2}$$

This formula has been applied to the standard score distributions, reducing the degrees of freedom by two, because of the constraints of equated Means and Sigmas.

[23] The N's of Part I have been increased over the 275 used previously so as to include more washouts. These cases had to be omitted from the correlational analysis because they did not have scores on all of the measures.

scores on Tidal Air Mean, Number of Cycles[24] and Oxygen Consumption. These are distributions with Means and Sigmas equated. They do not warrant combinations of Parts I and II, even if allowance is made for a different average and spread.

Treating each sample separately the probabilities that the scores of washouts differ from those of the total group only as a result of chance are obtained. These P's are given in Table XVIII. It had been thought that the failure to find any physiological differences between washouts and the total pilot population might have been due to the unreliability of the meausres employed. As far as respiration is concerned this does not seem to be the case. With measures that have demonstrated test and retest reliability and that have shown independent relations reliably the same in two different (and dissimilar) samples there is no strong probability that any respiratory difference is associated with the likelihood of being washed out. The demonstrated reliability is test-retest with no substantial interval of time. There is still the possibility that tests repeated often enough throughout a longer period of time will be correlated with pilot aptitude.

TABLE XVIII

THE PROBABILITY THAT WASHOUTS FOR APTITUDE ARE NOT SIGNIFICANTLY DIFFERENT FROM ALL PILOTS IN THEIR SCORES ON THE RESPIRATORY VARIABLES

| Respiratory Variable | P | $\chi^2$ | Degrees of Freedom | N of wash-outs | N of Parent Distribution |
|---|---|---|---|---|---|
| | | PART I | | | |
| Tidal Air Mean | .25 | 6.6 | 5 | 36 | 299 |
| Tidal Air Sigma | .62 | 4.4 | 6 | 36 | 299 |
| No. of Cycles | .06 | 7.3 | 5 | 36 | 299 |
| $O_2$ Consumption | .82 | 2.2 | 5 | 27 | 282 |
| Vital Capacity | .10 | 7.7 | 4 | 34 | 294 |
| | | PART II | | | |
| Tidal Air Mean | .11 | 5.5 | 7 | 60 | 371 |
| Tidal Air Sigma | .93 | 1.9 | 6 | 60 | 371 |
| No. of Cycles | .93 | 1.3 | 5 | 60 | 371 |
| $O_2$ Consumption | .03 | 12.4 | 5 | 60 | 371 |
| Vital Capacity | .79 | 2.4 | 5 | 60 | 371 |

The washouts of Part I differ in Number of Cycles but those of Part II definitely do not. Conversely, the washouts of Part II are significantly different in Oxygen Consumption, but those of Part I are conclusively not.

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[24]The balance of analysis uses No. of Cycles from the second test, the source for all of the other variables. No. of Cycles (1), was employed in the correlations to get rid of spurious relations due to chance errors occurring in both parties to a relationship.

It is possible, of course, that emphasis on different causes of failure was shifted between the two samples but from these data we cannot accept either of these measures as means of distinguishing flying aptitude. Tidal Air Mean has a low but not a sufficiently low P in both samples.

Inspection of the observed and expected distributions of washouts used in obtaining the chi's-squared (Appendix III) suggests that better criteria of flying failure (accidents, incapacity for altitude flying, etc.) and respiratory measures extended over time might reveal better predictive value in these respiratory measures. The best measure in Part I data is the rate of breathing measured by Number of Cycles. Extremely rapid breathing is more prevalent and extremely slow breathing less prevalent among washouts than among the total group. Oxygen Consumption differentiates significantly in the Part II sample because very large and very small oxygen usage is more characteristic of washouts. Average consumption is less characteristic. The Tidal Air Mean comparison is confused by the difference between the two samples. In Part I the washouts consistently have lower scores and in Part II they consistently have higher scores than would be expected from the distribution of the parent populations for this measure of volume of air breathed.

These are suggestive of reasonable influences on flying aptitude but it must be remembered that they are suggestive only. We have no respiratory measure which, from these data, could be accepted as having a predictive function in the selection of pilots. The study prompts a recommendation that these selected measures together with reliable cardiovascular measures be applied over sufficient time to permit definite evidence of their relation to pilot aptitude.

## SUMMARY AND CONCLUSIONS

Two consecutive eight-minute respiratory records were secured from two samples of student pilots in training at the Pensacola Naval Air Station, Pensacola, Florida. This report has presented the results of an extensive statistical analysis of these records undertaken with the view of providing accurate information as to the reliability, interdependence, and validity of various measures of respiratory functions available from these records. In all, 23 possible measures were investigated. On the basis of those analyses, it is possible to draw the following tentative conclusions:

1. The second two minutes of the eight-minute respiratory record is the best single time interval on which to secure the respiratory measures.

2. Of the 23 possible measures of respiration, only Tidal Air Mean, Tidal Air Sigma, Number of Cycles, Vital Capacity, and Oxygen Consumption possess sufficient reliability and independence (both mathematically and physiologically) to justify their use as measures of the respiratory functions.

3. These five measures may be accounted for by three factors: Factor A, made up primarily of the Tidal Air Measures with Number of Cycles contributing significantly; Factor B, composed mainly of the function of Vital Capacity with number of cycles also positively weighted; and Factor C, accounted for by Oxygen Consumption with a small contribution from the Tidal Air Sigma.

4. These factors bear no direct relation to the subjects' somatotype scores, their electroencephalographic scores, or measures of their cardiovascular function derived during a tilt table experiment.

5. None of the five selected respiratory variables bears a significant relationship to success in flight training, i.e., none of the measures will discriminate between washouts and all pilots.

6. There remains the possibility that analysis of larger samples of respiratory behavior than were employed in this study would yield different results. It is, therefore, recommended that the selected respiratory measures together with the reliable cardiovascular measures be applied over a sufficient period of time to permit definite evidence of their relation to pilot aptitude.

# APPENDIX I

## CHARACTERISTICS OF $r\,\frac{Z}{r}\,Y$

## APPENDIX 2

Differences like $(x - y)$ and ratios like $x/y$ have similar intentions. Differences present a simpler statistical problem and will, therefore, be considered first.

It may be shown algebraically that there is no correlation between y and the residuals of x from y.

$$\Sigma\left[y\left(x - r_{xy}\frac{\sigma_x}{\sigma_y}y\right)\right] \quad \text{(being the numerator of the correlation coefficient)}$$

$$= \Sigma xy - \Sigma y^2 r_{xy}\frac{\sigma_x}{\sigma_y}$$

$$= Nr_{xy}\sigma_x\sigma_y - N\sigma_y^2 r_{xy}\frac{\sigma_x}{\sigma_y}$$

$$= Nr_{xy}\sigma_x\sigma_y - Nr_{xy}\sigma_x\sigma_y = 0$$

This is because any array of x (having one y value) has as many positive as negative residuals and in normal linear materials they will be balanced in size.

However, the correlation between $(x - y)$ and $y$ is not always zero.

$$r_{(x-y)y} = \frac{\Sigma(x-y)y}{N\sigma_{x-y}\sigma_y} = \frac{\Sigma xy - \Sigma y^2}{N\sigma_{x-y}\sigma_y}$$

$$= \frac{Nr_{xy}\sigma_x\sigma_y - N\sigma_y^2}{N\sigma_{x-y}\sigma_y}$$

$$= \frac{r_{xy}\sigma_x - \sigma_y}{\sigma_{x-y}}$$

When sigmas are equal and r is 1.00 this correlation is zero. When sigmas are equal and $r_{xy}$ is less than 1.00, then the correlation must be negative. When $r_{xy}$ is zero and the sigmas are one the negative correlation is:

$$\frac{r_{xy}\sigma_x - \sigma_y}{\sqrt{\sigma_x^2 + \sigma_y^2 - 2r_{xy}\sigma_x\sigma_y}} = \frac{-1.00}{\sqrt{2}}$$

$$= -.7$$

This is a spurious relation in the sense that it depends entirely upon the relation of x to y. Since x and y are unrelated it follows that (x - y) must grow smaller as y grows larger. For example:

| Y | X | X - Y |
|---|---|---|
| 1 | 1, 2, 3, 4 | 0, 1, 2, 3 |
| 2 | 1, 2, 3, 4 | -1, 0, 1, 2 |
| 3 | 1, 2, 3, 4 | -2, -1, 0, 1 |
| 4 | 1, 2, 3, 4 | -3, -2, -1, 0 |

Now as $r_{xy}$ approaches 1.00 from zero the negative relation of (x-y) with y is reduced toward zero.

As an example, a common reference to the relation of "change in pulse due to exercise" and "terminal pulse" may be cited. This is a relation of (x-y) with y. When variance is equated it is wholly dependent upon the correlation of x with y. This is equally true of the relation between (x-y) with x. The formula $(x - r_{xy}\frac{\sigma_x}{\sigma_y}y)$ not (x-y) should be used. These residuals are zero with y and $\sqrt{1-r^2_{xy}}$ with x.[25]

When this logic is applied to ratios instead of to subtractions a complication, curvilinearity, is added. X/y is curvilinear in respect to y when x and y are linear in respect to each other.

| x | y | x/y |
|---|---|---|
| 1 | 5 | .2 |
| 2 | 6 | .33 1/3 |
| 3 | 7 | .43 |
| 4 | 8 | .50 |
| 5 | 9 | .55 |

Using the same zero correlation example with ratios as the one given above with differences, the following are obtained:

| y | x | x/y |
|---|---|---|
| 1 | 1,2,3,4 | 1,2,3,4 |
| 2 | 1,2,3,4 | .5, 1, 1.5, 2 |
| 3 | 1,2,3,4 | .33, .67, 1, 1.33 |
| 4 | 1,2,3,4 | .25, .5, .75, 1 |

The negative relation between y and x/y is apparent when the correlation of x with y is zero. The curvilinear aspect of the relation with the ratio is also apparent. In the case of a zero xy correlation because x is

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25 $$r_{x(x - r_{xy}\frac{\sigma_x}{\sigma_y}y)} = \frac{\Sigma x^2 - \Sigma xy\, r_{xy}\frac{\sigma_x}{\sigma_y}}{N\sigma_x\sigma_x\sqrt{1-r^2_{xy}}} = \frac{N\sigma_x^2 - Nr_{xy}\sigma_x\sigma_y r_{xy}\frac{\sigma_x}{\sigma_y}}{N\sigma_x^2\sqrt{1-r^2_{xy}}} = \frac{1-r^2_{xy}}{\sqrt{1-r^2_{xy}}} = \sqrt{1-r^2_{xy}}$$

a constant [illegible] of $\frac{x}{y}$ [illegible] by $\frac{x}{y}$ is negative increasing in value as increasing values of y reduce the curvilinearity of $\frac{x}{y}$.

The relation of x with y must be a second degree curve in order to obtain a linear relation between y and x/y.

| y | x/y | x | Δ |
|---|---|---|---|
| 1 | 4 | 4 | 6 |
| 2 | 5 | 10 | 8 |
| 3 | 6 | 18 | 10 |
| 4 | 7 | 28 | 12 |
| 5 | 8 | 40 | |

It is apparent that (x - y) and x/y are functions of the correlation between x and y. They should be used as variables in prediction work only when we can definitely justify them. The justifications for x/y are:

(1) That x and y are curvilinear in respect to each other so that x/y presents linear progression of [illegible].

(2) That the $\sigma$'s of arrays of the numerator grow larger with progressions in the denominator.

(3) That we are not using both x and y as a multiple combination because in that case $(x - r_{xy}\frac{\sigma_x}{\sigma_y}y)$ is far preferable and is implicit in the multiple.

The last of these applies to the difference as well as to the quotient.

# APPENDIX II

## FREQUENCY DISTRIBUTION OF PART I AND PART II CASES ON FIVE SELECTED RESPIRATORY MEASURES

## APPENDIX II

### FREQUENCY DISTRIBUTION OF PART I AND PART II ON FIVE SELECTED RESPIRATORY MEASURES

| Standard Deviation Interval | Tidal Air Mean I | Tidal Air Mean II | Tidal Air Sigma I | Tidal Air Sigma II | No. of Cycles I | No. of Cycles II | Oxygen Consumption I | Oxygen Consumption II | Vital Capacity I | Vital Capacity II |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.8 & above | 11 | 20 | 19 | 24 | 24 | 14 | 16 | 20 | 12 | 22 |
| 1.7 to 1.3 | 19 | 23 | 12 | 14 | 15 | 20 | 18 | 19 | 24 | 20 |
| 1.2 to 1.0 | 11 | 16 | 11 | 21 | 17 | 24 | 11 | 18 | 15 | 21 |
| .9 to .7 | 18 | 27 | 19 | 20 | 13 | 31 | 16 | 27 | 16 | 29 |
| .6 to .4 | 26 | 38 | 25 | 18 | 25 | 40 | 23 | 38 | 30 | 33 |
| .3 to .1 | 21 | 32 | 31 | 46 | 40 | 49 | 24 | 33 | 37 | 45 |
| 0 | 14 | 10 | 13 | 13 | 12 | 25 | 9 | 34 | 12 | 11 |
| -.1 to -.3 | 56 | 43 | 38 | 50 | 36 | 46 | 40 | 53 | 31 | 49 |
| -.4 to -.6 | 52 | 62 | 46 | 41 | 36 | 16 | 57 | 38 | 37 | 48 |
| -.7 to -.9 | 48 | 43 | 50 | 65 | 27 | 34 | 31 | 28 | 28 | 28 |
| -1.0 to -1.2 | 24 | 44 | 30 | 50 | 24 | 34 | 19 | 27 | 21 | 30 |
| -1.3 to -1.7 | - | 13 | 6 | 9 | 27 | 24 | 17 | 29 | 25 | 24 |
| -1.8 and less | - | - | - | - | 4 | 14 | 1 | 7 | 6 | 11 |
| N | 300 | 371 | 300 | 371 | 300 | 371 | 282 | 371 | 294 | 371 |
| M | 41.0 | 46.3 | 7.7 | 7.4 | 10.4 | 11.2 | 268.5 | 257.5 | 279.8 | 276.1 |
| Sigma | 15.5 | 15.4 | 4.4 | 4.1 | 3.4 | 3.2 | 44.8 | 31.8 | 34.4 | 34.9 |

## APPENDIX III

OBSERVED AND EXPECTED DISTRIBUTIONS OF WASHOUTS EMPLOYED IN COMPUTING CHI-SQUARED OF WASHOUTS IN RELATION TO ALL PILOTS (FOR EACH OF THE FIVE SELECTED RESPIRATORY VARIABLES)

# APPENDIX III

## OBSERVED AND EXPECTED DISTRIBUTION OF WASHOUTS EMPLOYED IN COMPUTING CHI-SQUARED OF WASHOUTS IN RELATION TO ALL PILOTS (FOR EACH OF THE FIVE SELECTED RESPIRATORY VARIABLES)

### TIDAL AIR MEAN

| Standard Deviation Interval | Part I | | Part II | |
|---|---|---|---|---|
| | o | e | o | e |
| 1.8 and above | | | | |
| 1.7 to 1.3 | | | 9 | 6.9 |
| 1.2 to 1.0 | | | - | - |
| .9 to .7 | 5 | 7.1 | 7 | 7.0 |
| .6 to .4 | - | - | 10 | 6.1 |
| .3 to .1 | - | - | - | - |
| 0 | 4 | 7.2 | 5 | 6.8 |
| -.1 to -.3 | 5 | 6.7 | 7 | 7.0 |
| -.4 to -.6 | 11 | 6.3 | 10 | 10.0 |
| -.7 to -.9 | 7 | 5.8 | 7 | 7.0 |
| -1.0 to -1.2 | 4 | 2.9 | - | - |
| -1.3 to -1.7 | | | 5 | 9.2 |
| Total | 36 | 36.0 | 60 | 60.0 |

## OXYGEN CONSUMPTION

| Standard Deviation Interval | Part I | | Part II | |
|---|---|---|---|---|
| | o | e | o | e |
| 1.8 and above | | | | |
| 1.7 to 1.3 | 3 | 3.2 | 12 | 6.4 |
| 1.2 to 1.0 | - | - | - | - |
| .9 to .7 | - | - | 9 | 7.3 |
| .6 to .4 | 5 | 4.8 | - | - |
| .3 to .1 | - | - | 6 | 11.5 |
| 0 | 5 | 3.2 | - | - |
| -.1 to -.3 | 5 | 3.8 | 9 | 14.1 |
| -.4 to -.6 | 4 | 5.5 | - | - |
| -.7 to -.9 | - | - | 9 | 10.6 |
| -1.0 to -1.2 | - | - | - | - |
| -1.3 to -1.7 | - | - | - | - |
| -1.8 and less | 5 | 6.5 | 15 | 10.1 |
| Total | 27 | 27.0 | 60 | 60.0 |

## VITAL CAPACITY

| Standard Deviation Interval | Part I | | Part II | |
|---|---|---|---|---|
| | o | e | o | e |
| 1.8 and above | | | | |
| 1.7 to 1.3 | | | 8 | 6.8 |
| 1.2 to 1.0 | | | - | - |
| .9 to .7 | | | - | - |
| .6 to .4 | 5 | 11.2 | 11 | 13.4 |
| .3 to .1 | 7 | 4.3 | - | - |
| 0 | - | - | 8 | 9.1 |
| -.1 to -.3 | 7 | 5.0 | 9 | 7.9 |
| -.4 to -.6 | - | - | - | - |
| -.7 to -.9 | 6 | 7.5 | 10 | 12.2 |
| -1.0 to -1.2 | - | - | - | - |
| -1.3 to -1.7 | - | - | - | - |
| -1.8 and less | 9 | 6.0 | 14 | 10.6 |
| Total | 34 | 34.0 | 60 | 60.0 |

TIDAL AIR SIGMA

| Standard Deviation Interval | Part I | | Part II | |
|---|---|---|---|---|
| | o | e | o | e |
| 1.8 and above | 4 | 2.3 | | |
| 1.7 to 1.3 | - | - | 8 | 6.2 |
| 1.2 to 1.0 | - | - | - | - |
| .9 to .7 | 5 | 5.2 | 8 | 6.7 |
| .6 to .4 | - | - | - | - |
| .3 to .1 | 4 | 8.9 | 11 | 10.3 |
| 0 | - | - | - | - |
| -.1 to -.3 | 4 | 6.4 | 8 | 10.2 |
| -.4 to -.6 | 7 | 5.7 | 7 | 6.7 |
| -.7 to -.9 | 7 | 6.1 | 8 | 10.4 |
| -1.0 to -1.2 | - | - | - | - |
| -1.3 to -1.7 | 6 | 4.4 | 10 | 9.5 |
| -1.8 and less | | | | |
| Total | 37 | 37.0 | 60 | 60.0 |

NUMBER OF CYCLES

| Standard Deviation Interval | Part I | | Part II | |
|---|---|---|---|---|
| | o | e | o | e |
| 1.8 and above | 6 | 2.9 | | |
| 1.7 to 1.3 | - | - | | |
| 1.2 to 1.0 | - | - | 10 | 9.4 |
| .9 to .7 | 5 | 5.4 | - | - |
| .6 to .4 | - | - | 14 | 11.5 |
| .3 to .1 | 9 | 7.8 | 7 | 7.9 |
| 0 | - | - | - | - |
| -.1 to -.3 | 7 | 5.7 | 9 | 11.4 |
| -.4 to -.6 | 5 | 4.4 | - | - |
| -.7 to -.9 | - | - | 9 | 8.1 |
| -1.0 to -1.2 | - | - | - | - |
| -1.3 to -1.7 | - | - | - | - |
| -1.8 and less | 4 | 9.8 | 11 | 11.7 |
| Total | 36 | 36.0 | 60 | 60.0 |