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A FACTOR ANALYSIS OF SOME CARDIOVASCULAR-RESPIRATORY VARIABLES WITH PARTICULAR REFERENCE TO THE SCHNEIDER AND THE McCURDY-LARSON TESTS

By

Leonard A. Larson

A Report on research conducted at Springfield College, Springfield, Massachusetts, 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.

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Committee on Selection and Training of Aircraft Pilots

July 23, 1943

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

Dear Dr. Brimhall:

Attached is a report by Leonard A. Larson entitled A Factor Analysis of Some Cardiovascular-Respiratory Variables with Particular Reference to the Schneider and McCurdy-Larson Tests. This is submitted by the Committee on Selection and Training of Aircraft Pilots with the recommendation that it be published in the Technical Series of the Division of Research, Civil Aeronautics Administration.

A critical review of the report indicates the need for a revised statistical treatment of the data which might well lead to changes in the content of the report. Instead of undertaking such a major operation at the present time, the report is presented as written by the author, together with an extensive Editorial Foreword based on comments made by the author, the referee, members of the Editorial Staff and others who have reviewed the study. Suggestions with respect to a further statistical analysis of the data are also presented in this Foreword.

Very truly yours,

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

MSV/ee

EDITORIAL FOREWORD

Early in the history of the Committee on Selection and Training of Aircraft Pilots, Dr. Leonard A. Larson undertook research involving a factor analysis of cardiovascular-respiratory variables, with particular reference to the Schneider Test and the McCurdy-Larson Test. The present report deals with the findings of the research conducted by Dr. Larson.

The report is published essentially as written by Dr. Larson. The editors, and also the author, are of the opinion that a considerable portion of the report would be of more value if rewritten in terms of a modified analysis and a more extensive treatment of the data. However, conditions make it impracticable to conduct the required statistical analysis and to rewrite the report at the present time. The report is therefore being published as written. In doing so, it seems desirable to call to the attention of the readers the following comments on the report, which represent the questions and criticisms raised by the author, referees, and editors in preparing it for publication.

1. As the author points out, cardiovascular-respiratory phenomena are probably manifold and not manifestations of one primary function. For this reason, as many physiological correlates as possible should have entered into the selection of measures and should have figured in the discussion of the factors themselves.

2. As in many studies of physiological phenomena, the same basic variable is included in more than one index or battery score. In factor analysis, the repetition of the same basic variable is itself a determinant of the kind of factors which may be isolated. While the use of such "repetitive" variables in factor analysis can be defended, its influence must be clearly recognized. It will be noted in this study that many of the intercorrelations and factor loadings are misleading for this reason. Even after the factors are rotated and "logically" clustered there still remains a great deal of overlap. The following are examples of such repetition:

a. Pulse pressure, derived only as the difference between systolic and diastolic blood pressure (i.e., it is not a unique measure) has been included both in the analysis and in the factors as an "independent variable."

b. Pulse pressure before exercise, pulse pressure after exercise, and change in pulse due to exercise (the difference between the two) have been included as three independent variables.

c. Sitting pulse, standing pulse, and pulse after exercise are all pulse measures, but more than that, are all in part a function of the individual's basic, initial pulse rate. The use of difference-scores (partialing out basic pulse) or the use of "weights" should be employed to make these variables as independent as possible.

3. When such repetitive variables are used, chance errors in measurement introduce a spurious element into correlations. There are many such spuriously high correlations in the original correlational matrix.

4. When the table of factor loadings is examined (Table II) in relation to the factors as described in the text, it will be noted that there are large positive and negative loadings on some of the items which have been neglected when the factors were "logically" clustered. In defining the "independent" factors, some items with a loading of .30 or over were disregarded when they did not seem to fit into the factors as described authoritatively. These have, on the other hand, been included when they did seem to agree with "authoritative opinion" as to how the variables should be clustered. Such a method of grouping the variables (with apparent disregard for the magnitude of the loading) seems inconsistent with the purposes of factor analysis. A possible explanation of many of these "unwanted" and "unused" loadings was offered in #2 on the previous page.

5. The paper does not contain a discussion of the possibility that the factors as isolated might be more closely inter-related were the individual differences more faithfully depicted by the measures. When the low reliability (test-retest correlation) of many physiological measures is considered, it is evident that a factorial study of this sort is an analysis of biological instants, and that if measures which were truly characteristic of individuals could be obtained, fewer factors might be isolated from any group of such physiological measures.

6. It will be noted that the majority of the h^2's are near 1.00. This would seem to indicate that these h^2's are probably not "true" estimates of the reliability, but are only indications of "plural bookkeeping."

7. One of the limitations indicated on page 4 is that the group is a select sample consisting of "Springfield College men, all of whom participated in physical educations activities." Actually, approximately 80% of the population consisted of students majoring in health and physical education, the remainder being non-major students exposed to considerably less physical activity. There is, of course, the distinct possibility that the population used in this study is not directly comparable to those used by the other investigators to derive their cardiovascular or efficiency test batteries.

8. The following techniques deserve consideration as a basis for further analysis of the data presented in this study:

a. The factors could be rerotated from the centroids thereby bringing the loadings nearer the usual form. Such a rotation would leave no "unexplainable" high negative loadings and no "unwanted" significant positive loadings.

b. One of the reasons that so many of these "unexplainable" high positive and negative loadings appear in the table may be that there are too many items (variables) included in the analysis for the 145 cases used. Further treatment of the data would take this into account. The first 19 (relatively independent) items could be refactored and a complete rotation done on these prior to the inclusion of the "batteries." The batteries could then be added by means of Dwyer's extension.[1]

c. Inasmuch as the variables as rotated in this study were treated as if they were "truly independent" their prediction by means of multiple correlation methods using tests with loadings on other factors must lead inevitably to correlations among "factor scores" unless something is done to eliminate the correlation. In this connection the variables included in these factors could be rescored using the factor weights, and the correlations between these "independent factor scores" computed. It is doubted if the points on the "profile" would be as independent as one is led to believe from the analysis in its present form if these correlations were done.

d. It might be desirable to set up new batteries of items by factor-scoring (weights determined by the factor loadings) the individual items which would measure the "separate factors" only by combining certain of the measures (items) and "partialing" out others from this combination. This procedure might well prove more useful than multiple regression equations with their enforced use of linear relationships only.

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[1] Dwyer, D. S. The determination of the factor loadings of a given test from the known factor loadings of other tests. Psychometrika, 1937, 2, 173-178.

CONTENTS

SUMMARY

The purposes of this study are: (1) to analyze selected cardio-vascular-respiratory variables for their principal components and (2) to determine the physiological characteristics of 10 selected cardiovascular test index scores on the basis of the isolated factors.

Nineteen cardiovascular-respiratory measures were obtained on 145 men majoring in health and physical education. Groups of these were combined into 10 cardiovascular tests batteries. The measures on the 19 relatively independent variables and 10 combined batteries were studied by means of factor analysis techniques and analyzed in relation to earlier findings in physiological research. There were revealed 8 primary factors:

1. Pulse pressure.
2. Pulse rate response to exercise in relation to normal.
3. Pulse rate response to exercise.
4. Pulse pressure in response to postural change.
5. Diastolic pressure and changes with respect to body position.
6. Respiratory function.
7. Blood pressure response to changes in position.
8. Systolic pressure.

Utilizing the results of factor analysis and in addition a logical analysis of the intercorrelations by competent authority, the following variables were selected as being sufficiently unrelated as to be considered independent ;

1. Horizontal pulse rate.
2. Differences between horizontal and standing pulse rates.
3. Differences between normal standing pulse rate and pulse rate two minutes after exercise.
4. Horizontal systolic pressure.
5. Differences between horizontal and standing systolic pressures.
6. Horizontal diastolic pressure.
7. Standing diastolic pressure.
8. Differences between horizontal and standing diastolic pressures.
9. Horizontal pulse pressure.
10. Differences between horizontal and standing pulse pressures.
11. Breath-holding twenty seconds after exercise.
12. Vital capacity.
13. McCurdy-Larson Efficiency Test.

The eight factors isolated in this research are not described by any one of the ten test batteries or "index scores." The reasons for this lack of relationship are:

1. The factor may not be included in the test battery.

2. The number of items in the battery may be so numerous that the influence of the factor is not reflected.

3. The system of scaling the items in the test batteries makes it impossible to compare identical items on various batteries.

4. The test battery may yield information not covered by one of the eight factors.

These results of this study must be interpreted in the light of certain limitations:

1. The variables and tests selected cannot be assumed to indicate a complete measure of the cardiovascular-respiratory functional status.

2. The isolated factors and their identification are on the basis of the variables used in the study and the judgment of physiologists.

3. A selected sample (physical education students) was used in this study and, therefore, may present unique cardiovascular determinants.

4. The test batteries used in the study cannot be directly compared because the variables are not identical. The system of rotation and identification of the factors involve judgment skill, i.e., the best rotation may not be made and the factors may be identical but given different names. Furthermore the data are on different institutional populations.

5. The variables and tests are not all completely described by the isolated factors. The 10 test batteries are described by the isolated factors in terms of their index scores. Reliabilities of the cardiovascular-respiratory variables are low.

6. The same basic variable is present in more than one of the index scores in batteries.

A FACTOR ANALYSIS OF SOME CARDIOVASCULAR-RESPIRATORY VARIABLES WITH PARTICULAR REFERENCE TO THE SCHNEIDER AND THE McCURDY-LARSON TESTS

INTRODUCTION

In the measurement of any ability, trait, or characteristic, the fundamental questions which arise are: (1) What constitutes the elemental components?, and (2) How may these be measured? The answers to these questions constitute basic research in knowledge about the ability, trait, or characteristic before application is made. In the measurement of cardiovascular-respiratory function, for example, how completely do the commonly used physiologic variables indicate functional integrity? Because there is no objective way of knowing when measurement of cardiovascular-respiratory function is complete, one must begin on the premise that all available measures are indicative, then analyze the variables for their elemental components and means of measurement of the components. The correlational method serves as a tool in this process with the intercorrelations analyzed by the factor analysis method and by an inspectional analysis of the intercorrelations.

The problem of sampling is important in any research, but has particular importance in correlation studies where the measurements are to be analyzed for elemental components. The data used must be homogeneous with respect to all sources of variance other than the observed measurement. In physiological variables the age factor, for example, must be eliminated. With the foreign factors eliminated one is ready to begin the correlational analysis. (See Procedure for factors eliminated in this study.)

In correlational studies of physiologic variables if a ratio is found to exist between minute volume and P.P. x P.R. for an individual, and this ratio is the same for <u>all</u> individuals in a homogeneous group, it can be assumed that the mechanism regulating these two measures is the same. In the selection of variables for the measurement of this function, one may be selected as it accurately predicts the other. The elemental component has been measured.

The experimental variables selected for this research are those commonly used (pulse rate, blood pressure, etc., with reactions to exercise), with the laboratory measures omitted (O_2 consumption, minute volume estimates, etc.). One of the major limitations of the research is that no assurance can be given, after an extensive statistical analysis, that all elemental components have been isolated. It yields information only with respect to the variables used and the accuracy with which the components have been isolated and identified.

There have been three studies reported on the analysis of the interrelationships of cardiovascular-respiratory variables to determine which items tend to vary together and to establish hypotheses as to the regulating mechanism.[1,2,3] The variables used in these reports are not identical; therefore exact comparisons of the studies cannot be made. Other limitations in factor analysis also prohibit exact comparisons.[4] (See Limitations.) Two of these studies were on college men[1,3] and one on college women. The purpose of these studies was to analyze the table of intercorrelations using the Thurstone Factor Analysis [5,6,7] method to determine the principal components, that is, the number of components describing the variables. An illustration will make clear the method: One may use 20 cardiovascular-respiratory variables in an examination and assume that they are unrelated, making 20 specific estimates of cardiovascular-respiratory function. One might assume that they are all perfectly related and that only one mechanism regulates function. It is, of course, obvious that neither of these two hypotheses is correct and that some number between these extremes describes the selected variables. Such an analysis is of tremendous significance in order to set the stage for experimental work as well as a means of selecting variables in the construction of cardiovascular-respiratory tests. A comprehensive evaluation of function status should include all unrelated factors.

McCloy[1] found in analyzing 14 cardiovascular variables that they were described by at least eight principal components. The variables included horizontal and standing systolic, diastolic, and pulse pressures; a comparison of pulse rate and pressures between the horizontal and standing positions; and pulse rate after exercise. Three of the isolated factors were identified as factors of pulse rate (heart rate, standing heart

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[1] McCloy, C.H. A study of cardiovascular variables by the method of factor analysis. Proceedings, Second Biennial Meeting, Society for Research in Child Development. Oct. 1936, pp. 107-113.

[2] Murphy, Mary A. A study of the primary components of cardiovascular tests. Res. Quart. of the Amer. Assoc. for Health, Physical Educ. & Rec. 1940, 11, 57-71.

[3] Quamme, H.J. A Factor Analysis of Cardiovascular Variables. Unpublished Master's Thesis, Springfield College, Springfield, Mass.

[4] A list of the individual variables as well as the factors identified in these three studies are presented in Appendix I. Selection of variables for inclusion in the present study was based on these analyses.

[5] Thurstone, L.L. Current issues in factor analysis. Psychol. Bull., 1940, 37, 189-236.

[6] ____________ A Simplified Multiple Factor Method. Chicago: The University of Chicago Book Store, 1933.

[7] ____________ The Vectors of Mind. Chicago: The University of Chicago Press, 1935.

rate, and heart rate return to normal), and five as factors of blood pressure (general blood pressure, pulse pressure, reclining diastolic pressure, effect of position on systolic, and reclining systolic pressure).

Murphy[8], utilizing 32 cardiovascular variables in examining a group of college women, found nine primary components. Three of the isolated factors were described as factors of pulse rate and six as blood pressure factors.

In a study conducted by Quamme[9] 20 cardiovascular-respiratory variables were analyzed by the factor method. Eight factors were isolated. Four were described as factors of pulse rate (circulatory recovery to exercise, effect of pulse rate to exercise, pulse rate return after exercise, and pulse rate response to postural changes), and four as factors of blood pressure (head or maximum pressure, diastolic changes with body position, diastolic pressure, and maximum pressure changes with body position).

STATEMENT OF PROBLEM

The purposes of this research are twofold: (1) to analyze some cardiovascular-respiratory variables for their principal components, and (2) to determine the physiological characteristics of ten selected cardiovascular test index scores on the basis of the isolated factors.

PROCEDURE

Experimental. Nineteen cardiovascular-respiratory variables were administered to 145 Springfield College men, the majority of whom were major students in health and physical education. Some of the variables were used to score ten cardiovascular tests. The total of 29 variables and tests was used in the statistical analysis. The nineteen variables served as material for the isolation and identification of the factors. The ten test batteries were included to determine their physiologic characteristics on the basis of the isolated factors. The following precautions were used in obtaining data for the statistical analysis: (1) no exercise was allowed before the examination (during that day); (2) subjects with emotional disturbances were not used; (3) subjects not receiving a normal amount of sleep the night previous to the examination were eliminated; (4) subjects with heart defects (medical examination) were not used; (5) subjects having a heavy meal just before the examination were asked to return in one hour; (6) subjects with colds were not used; and (7) the subjects selected represent a physically fit group of young men (18-24 years of age), all of whom participated in physical education activities as part of their education. The measurements were all made in one week in September. All questionable results were rechecked and were dropped or retained on the basis of the above criteria.

Statistical. The Thurstone Method of Factor Analysis[10] was used

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[8] Op. cit.

[9] Op. cit.

[10] See references on page 2.

in the isolation of the factors. This method begins with a table of intercorrelations (406 rectilinear correlations in this problem) and results in the isolation of a number of factors or components which constitute the major part of the tests analyzed and gives a correlation between the factor and the tests used in the analysis. The method assumes that the tests and variables are related and that they can be described by a relatively small number of factors. The factor method involves no assumption as to the nature of the factors. The name given to the factor, or identification, is determined by how much one knows about the tests and the field within which he works. In this research two outstanding physiologists have reviewed the statistical results and have given suggestions as to the nature of the factors isolated.

Limitations. In the interpretation and application of the results of this research the following should be considered: (1) the variables and tests selected cannot be assumed to indicate a complete measure of the cardiovascular-respiratory functional status; (2) the isolated factors and their identification are on the basis of the variables (not test batteries) used in the study and the judgment of physiologists; (3) the sample consists of Springfield College men from 18 to 24 years of age, all of whom participated in physical education activities (see Editorial Review); (4) the factor analysis studies reviewed cannot be directly compared because the variables are not identical, the system of rotation and the identification of the factors involve judgment skill; that is, the best rotation may not be made and the factors may be identical but given different names, and the data are on different institutional populations and on men and women; (5) the variables and tests are not all completely described by the isolated factors. Factors will appear only if they are present in at least two of the tests analyzed. Because some of the tests are not completely described by the isolated factors, the implication is that other factors are possible; (6) the ten test batteries are described by the isolated factors in terms of their "index scores"; and (7) the reliability range of the cardiovascular-respiratory variables and tests is .75 to .95, which means that a high degree of confidence as to the stability of the factor cannot be made. (See Editorial Review for other limitations.)

RESULTS

The results of the factor analysis of the table of intercorrelations (Table I) show that there is no common factor; that is, a factor common to all variables and tests used in this analysis (Table II). The eight isolated factors are described by independent clusters of variables, which give evidence that cardiovascular-respiratory variables are sufficiently independent or unrelated so that at least eight factors are necessary to describe cardiovascular-respiratory function. The eight factors cannot be considered entirely independent or entirely unrelated, but they are not sufficiently related for cross prediction.

TABLE II

ROTATED FACTOR LOADINGS OF CARDIOVASCULAR-RESPIRATORY VARIABLES AND TESTS

	I	II	III	IV	V	VI	VII	VIII	Rotated h^2	Unrotated h^2
1. Hor.P.R.	.082	.127	.723	.226	-.224	.169	-.040	-.256	.742	.742
2. Std.P.R.	.002	-.196	.829	-.151	.131	.129	-.113	-.447	.994	.993
3. Hor.S.P.	.387	.141	.217	-.215	-.044	-.270	-.524	.603	.865	.865
4. Hor.D.P.	-.505	.176	.347	.444	-.018	-.260	-.319	.214	.818	.818
5. Hor.P.P.	.687	.027	-.111	-.573	-.101	-.053	-.013	.256	.893	.892
6. Sit.S.P.	.327	.070	.296	-.078	-.055	-.209	-.461	.649	.887	.887
7. Sit.D.P.	-.569	.039	.308	.084	-.287	-.310	.041	.518	.875	.875
8. Sit.P.P.	.760	-.067	.052	-.128	-.278	.029	-.462	.203	.934	.935
9. Std.S.P.	.221	-.038	.374	-.037	-.100	-.073	-.064	.847	.928	.929
10. Std.D.P.	-.677	-.109	.279	-.086	-.357	-.092	-.150	.454	.920	.920
11. Std.P.P.	.858	.085	.202	.060	.136	.013	.005	.450	1.009	1.009
12. V.C.	-.110	.046	-.067	-.229	.213	.358	-.275	.229	.373	.372
13. B.H. aft. Ex.	-.164	.135	-.245	-.077	.159	.560	-.317	.173	.580	.580
14. P.R. 2 min. aft.ex.	.026	.357	.851	-.213	-.148	.100	.046	-.246	.992	.991
15. Diff.Std. P.R.&P.R. 2 min.aft Ex.	.084	.598	.383	-.146	-.270	-.012	.197	.073	.649	.649
16. Diff.Hor. Std.P.R.	-.088	-.378	.173	-.377	.159	.046	-.377	-.309	.589	.588
17. Diff.Hor. Std.S.P.	-.113	-.248	.363	.235	-.176	.272	.480	.543	.892	.892
18. Diff.Hor. Std.D.P.	-.180	-.291	-.058	-.559	-.432	.170	.268	.237	.776	.776
19. Diff.Hor. Std.P.P.	.068	-.019	.339	.749	-.290	.041	.064	.149	.796	.796
TEST BATTERIES										
20. McCloy Test	-.442	.027	-.444	.104	-.364	-.123	-.002	.610	.924	.924
21. Barach Test	-.11[illegible]	-.227	.849	-.121	-.030	.090	-.126	.074	.830	.830
22. Stone Test	.749	-.068	-.041	-.068	-.317	.181	-.295	-.133	.910	.809
23. Basal Metab. Test	.607	-.102	.757	-.054	.189	.118	-.039	.019	1.007	1.007
24. Tigerstedt Test	.909	.070	.106	.109	.234	.066	.089	.200	.961	.961
25. P.P.xP.R. (Std.)	.788	-.041	.528	.005	.168	.060	-.001	.243	.992	.992
26. P.P.xP.R. ÷ Dias.(Std.)	.888	.009	.356	.031	.247	.050	.038	.055	.983	.983
27. Crampton Test	-.042	.018	.230	.365	-.373	.256	.452	.561	.913	.913
28. Schneider Test	-.085	-.141	-.386	.173	-.226	.011	.201	.615	.676	.676
29. McCurdy-Larson Test	-.343	.168	-.133	-.080	.314	.486	-.190	.318	.642	.642

TABLE III

MULTIPLE CORRELATION OF VARIABLES WITH THE FACTORS

Factor	Variables in the Factor*	Multiple Correlations	
I Pulse Pressure	5. Horizontal pulse pressure. 8. Sitting pulse pressure. 11. Standing pulse pressure.	$R_{I.5,8,11}$ $R_{I.8,11}$	= .894 = .891
II Pulse rate response to exercise in relation to normal	14. Pulse rate 2 minutes after exercise. 15. Difference in standing pulse rate and pulse rate 2 minutes after exercise. 16. Difference in horizontal and standing pulse rate.	$R_{II.14,15,16}$	= .654
III Pulse rate response to exercise.	1. Horizontal pulse rate. 2. Standing pulse rate. 14. Pulse rate 2 minutes after exercise.	$R_{III.1,2,14}$ $R_{III.2,14}$	= .893 = .892
IV Pulse pressure in response to postural change	4. Horizontal diastolic pressure. 18. Difference in horizontal and standing diastolic pressure. 19. Difference in horizontal and standing pulse pressure.	$R_{IV.4,10,19}$	= .775
V Diastolic pressure and changes with respect to body position	7. Sitting diastolic pressure. 10. Standing diastolic pressure. 18. Difference in horizontal and standing diastolic pressure. 19. Standing pulse pressure.	$R_{V.7,10,18,19}$ $R_{V.7,10}$	= .740 = .744
VI Respiratory factor	12. Vital capacity. 13. Breath holding after exercise.	$R_{VI.12,13}$	= .577
VII Blood pressure response to changes in posture	3. Horizontal systolic pressure. 4. Horizontal diastolic pressure. 6. Sitting systolic pressure. 8. Sitting pulse pressure. 17. Difference in horizontal and standing systolic pressure.	$R_{VII.3,4,6,8,17}$ $R_{VII.4,6,8,17}$ $R_{VII.4,8,17}$	= .865 = .864 = .864
VIII Systolic pressure	3. Horizontal systolic pressure. 6. Sitting systolic pressure. 9. Standing systolic pressure. 17. Difference in horizontal and standing systolic pressure.	$R_{VIII.3,6,9,17}$ $R_{VIII.6,9,17}$ $R_{VIII.9,17}$	= .864 = .864 = .862

* The Arabic number preceding the name of the variable corresponds to the numbers of the variables as listed in Tables I and II.

With the aid of expert physiologists[11] the eight isolated factors were analyzed and physiologically described. The single variables were statistically analyzed to determine their "net" contribution to each factor. Those yielding significant "net" contributions were selected as predictive of the factor. The multiple correlations (Table III) indicate the significance of the prediction and were used as an aid in the identification of the factors.[12] It will be noted (Table II) that the variables are not all completely described by the eight factors. This means that the tests which are not described are specific with respect to the variables in this experiment. Unless a factor is found in at least two tests, it cannot be isolated.

The process of factor rotation involved only the simple variables and did not include the test batteries. The test batteries were included only for the purpose of determining their physiologic characteristics on the basis of the isolated factors. (See Editorial Review on spurious factors.)

Factor One: This factor because of the high loadings (correlations) of sitting and standing pulse pressures (.76, .86) is identified as pulse pressure. The multiple correlation of these two variables with the factor is .89. The horizontal pulse pressure correlates .69 and diastolic pressure (horizontal, sitting, and standing) also correlates significantly. The intercorrelations of diastolic pressure and pulse pressure, however, are not sufficiently high to predict one, given the other. Pulse pressure must therefore be considered as a single component when compared with the other cardiovascular-respiratory measures.

Factor Two: The physiologic variables correlating significantly with this factor are: pulse rate two minutes after exercise (.36), the difference between standing pulse rate and pulse rate two minutes after exercise (.60), and the difference between horizontal and standing pulse rates (-.38). The multiple correlation of these variables is .65. This factor is therefore described as pulse rate response to exercise in relation to normal and is considered unrelated to the other physiologic factors.

Factor Three: The variables correlating significantly with factor three are horizontal pulse rate (.72), standing pulse rate (.83), and pulse rate two minutes after exercise (.85). The "net" contribution of the horizontal pulse rate in the presence of standing pulse rate and pulse rate two minutes after exercise is insignificant. The multiple correlation of the remaining two tests is .89. The factor is described as pulse rate response to exercise and is also sufficiently unrelated to the other isolated factors.

Factor Four: The variables significantly related to the factor are horizontal diastolic pressure (.44), horizontal pulse pressure (-.57), difference between horizontal and standing diastolic pressures (-.56), and the difference between horizontal and standing pulse pressures (.75). On the basis of this evidence it is described as pulse pressure in response to postural change. The multiple correlation of these variables (eliminating horizontal pulse pressure) is .78, and it is considered unrelated to the other factors.

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[11] The writer wishes to express appreciation to P.V. Karpovich, M.D., and Percy Dawson, M.D., for their description of the isolated factors.

[12] The multiples were developed by means of the Fisher-Dolittle multiple correlation technique using the factor loadings as zero order correlations.

Factor Five: The physiologic variables correlating significantly are: sitting diastolic pressure (-.29), sitting pulse pressure (-.28), standing diastolic pressure (-.36) difference between horizontal and standing diastolic pressures (-.43), and the difference between horizontal and standing pulse pressures (-.30). Sitting and standing diastolic pressures have the largest "net" significance in predicting the factor (.74). It is described as diastolic pressure and changes with respect to body position and is considered unrelated to the other factors.

Factor Six: Vital capacity and breath-holding 20 seconds after exercise correlate significantly (.36 and .56). These items yield a multiple correlation of .58 and are described as the respiratory factor. The multiple correlation is not significantly high to effectively predict the factor, however, the items are not significantly related to the other components; therefore it can be considered another aspect of cardiovascular-respiratory function.

Factor Seven: The items correlating significantly are: horizontal systolic pressure (-.52), horizontal diastolic pressure (-.32), sitting systolic pressure (-.46), sitting pulse pressure (-.46), and difference between horizontal and standing systolic pressure (.48). The multiple correlation between horizontal diastolic pressure, sitting pulse pressure, difference between horizontal and standing systolic pressure and the factor is .85. It is described as blood pressure response to changes in posture. The identification, however, is with a low degree of confidence because of the lack of sufficient degree of differentiation of the various pressures.

Factor Eight: The variables correlating are all systolic pressures in the various positions (horizontal, sitting, and standing). Standing systolic pressure and the difference between the horizontal and standing systolic pressure correlate (multiple) .86. It is identified as systolic pressure. It is considered unrelated with the other factors.

INTERPRETATION OF CARDIOVASCULAR TEST "INDEX SCORES" IN TERMS OF THE IDENTIFIED FACTORS

One of the major purposes of this analysis is to determine the physiologic characteristics of the ten selected cardiovascular test "index scores" with particular reference to the Schneider and the McCurdy-Larson tests. The "index scores" were therefore included in the factor analysis. This procedure does not establish the validity of these batteries as validity can be established only by its evaluation with respect to an acceptable criterion, but it simply yields a physiologic description on the basis of the identified factors. The procedure also assumes that the isolated factors resulting from the analysis of the single cardiovascular-respiratory variables are correctly identified. An example illustrates the use of the factor method in the analysis of the test batteries. A cardiovascular test battery is a complex phenomenon. We are interested in two characteristics of this battery: (1) What is its validity? and (2) What are its physiologic characteristics? It is in the latter that the factor analysis procedure makes a contribution. If, for example, it is found that three pure factors correlate perfectly with the test battery, it can be assumed that the test battery is fully described by the three factors, and if the factors are correctly identified, the description of the test battery is established. So it is in this analysis. If diastolic pressure correlates perfectly with a test battery, the test battery is physiologically the same as diastolic pressure, assuming that no other variables are reacting on both the test battery and diastolic pressure to produce the perfect correlation. If a large portion of the relationship is due to age, it would be hardly correct to say that the correlation is perfect between the diastolic pressure and the test battery. For a complete physiologic description it is necessary to know what constitutes the relationship. If the variables could all be assumed to be pure this problem would be eliminated, but this cannot be assumed to be true in circulatory-respiratory variables.

In Table IV the relationships between the eight isolated cardiovascular factors and the various test batteries have been listed in terms of significant correlations. It is noted that Factor I (Pulse Pressure) correlates significantly with five test batteries (Stone .75, Basal Metabolic .61, Tigerstedt .91, P.P. x P.R. .79, and P.P. x P.R.$\frac{1}{2}$ Dias. .89). The reason for such correlations is apparent as the tests have for their major constituent pulse pressure. The pulse pressure factor yields nearly a complete description of the three tests. The descriptions by the other seven isolated factors are hardly significant, with the exception of the Basal Metabolic Test and the P.P. x P.R. which correlate .76 and .53, respectively, with Factor three (pulse rate response to exercise). (See Editorial Review on multiple r's.)

Factor two (pulse rate response to exercise in relation to normal) does not correlate significantly with any of the ten cardiovascular test batteries. The factor is included in some of the test batteries but the influence of this variable on the index score appears to be lost in the summing process. This is an important and comparatively unrelated factor.

The Barach Test (.85), the Basal Metabolic Test (.76) and the P.P. x P.R. Test (.53) all correlate significantly with factor three (pulse rate response to exercise). These tests all include this component as a major constituent. The factor is included in some of the other batteries (McCloy and Schneider), but the index scores of these tests do not reflect it.

The Crampton Test is the only test correlating with factor four (pulse pressure in response to postural change) (.37). This test does not include the factor, but the slightly significant correlation is probably due to the relationship of the factor to systolic pressure postural change, which is a major element of the test. These two factors are related to approximately this degree.

Factor five (diastolic pressure and changes with respect to body position) correlates slightly with four tests (McCloy, Stone, Crampton, and the McCurdy-Larson Test). The signs are not consistent in the McCurdy-Larson Test, but this may be due to the system used in scaling the diastolic pressure. The high and low diastolic values receive a low index score in the McCurdy-Larson Test. The factor is rotated as a negative factor; therefore the positive relationship with the McCurdy-Larson Test.

TABLE IV

PHYSIOLOGIC DESCRIPTION OF CARDIOVASCULAR TESTS BY IDENTIFIED FACTORS

Identified Factors	Significant Correlations with Tests And Identified Factors: Test	Correlation
1. Pulse Pressure	1. Stone	.749
	2. Basal Metabolic	.607
	3. Tigerstedt	.909
	4. P.P. x P.R.	.786
	5. P.P. x P.R. ÷ Dias.	.886
2. Pulse Rate Response to Exercise in Relation to Normal		No significant correlations
3. Pulse Rate Response to Exercise	1. Barach	.849
	2. Basal Metabolic	.757
	3. P.P. x P.R.	.523
4. Pulse Pressure in Response to Postural Change	1. Crampton	.365
5. Diastolic Pressure and Changes with Respect to Body Position	1. McCloy	-.364
	2. Stone	-.317
	3. Crampton	-.373
	4. McCurdy-Larson	.314
6. Respiratory Function	1. Crampton	.256
	2. McCurdy-Larson	.486
7. Blood Pressure Response to Changes in Position	1. Stone	-.295
	2. Crampton	.452
8. Systolic Pressure	1. McCloy	.610
	2. Crampton	.561
	3. Schneider	.615
	4. McCurdy-Larson	.318

The respiratory factor (six) correlates significantly (.49) with the McCurdy-Larson Test and slightly with the Crampton Test. The McCurdy-Larson Test correlates because of vital capacity and breath-holding ability 20 seconds after exercise; the Crampton Test because of the relationship of pulse rate to the factor. The correlations with the other tests are zero.

Factor seven (blood pressure response to changes in position) correlates significantly with the Crampton Test and slightly and negatively with the Stone Test. This is in accord with the nature of the factor and tests. The difference in the horizontal and the standing systolic pressures is a positive element of the factor and one of its significant elements. The Crampton Test includes this element, and also correlates positively with the factor. The horizontal systolic pressure has a negative correlation with the factor which indicates that, as the factor increases, the horizontal systolic pressure decreases. The sitting pulse pressure correlates with the factor, and this item is the major constituent of the Stone Test, therefore, the negative correlation.

Factor eight (systolic pressure) describes partially the McCloy Test (.61), the Crampton Test (.56), the Schneider Test (.61), and the McCurdy-Larson Test (.32). The correlations are significantly higher in the first three tests. The Crampton and the Schneider Tests include this factor as a major component. In the McCloy Test, however, the only account which can be made is the relationship of systolic pressure to diastolic pressure in the standing position.

It will be noted in Table II that the eight isolated factors describe six of the ten test batteries from 90 percent to 100 percent,[13] two from 80 to 90 percent, and two from 60 percent to 70 percent. It is also interesting to note that not one of the test batteries reflects all eight isolated factors. The test correlating significantly with each of the eight isolated factors vary from one to five. The correlations, however, are not sufficiently high to predict the factor. It should be pointed out that the reason the tests may not reflect the various components may be because of the system of scaling. For example, diastolic pressure in the McCurdy-Larson Test is scaled according to the logical physiological interpretation; that is, the mean is used as the desirable value (best score) with the extremes as the undesirable values (low scores). The unscaled diastolic pressure will therefore not correlate with the scaled value.[14] The index score, therefore may have a higher degree of validity, as an estimate of circulatory-respiratory function, than is reflected by its correlation with the factor.

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13 The factor loadings squared are interpreted as percentages.

14 Editor's Note. The correlation between values on the two scales will be curvilinear. This fact suggests that all correlations between the McCurdy-Larson Test and unscaled pressure measures should be carefully examined for linearity. The author reports, in a comment upon this point: "In those scatter-diagrams prepared the McCurdy-Larson Test correlations were found linear. This is also reasonable to assume physiologically."

IMPLICATIONS OF THE FACTOR ANALYSIS TO TEST CONSTRUCTION

The results of the factor analysis of the 20 variables and tests indicate two conclusions: (1) the selection of variables for the construction of the ten test batteries does not include all the factors describing circulatory-respiratory function, and (2) the "index scores" of the ten selected tests do not reflect the isolated factors of circulatory-respiratory function. It was also found that in some test batteries, where the factor represents a major part of the battery, the "index score" does not reflect it to a significantly high degree. This is because of the influence of the other items in the battery. It does not necessarily mean that these tests are invalid with respect to a specific objective, but it does mean that they are invalid as a complete index (in terms of the selected variables) of circulatory-respiratory status.

The implications of these findings to test construction are three: (1) the selection of the items for the complete estimate of cardiovascular-respiratory function should include all factors of these systems; (2) if some of the factors are to be eliminated, this must be done in terms of a specific criterion, which represents the use to be made of the selected factors; and (3) the sum of a number of cardiovascular-respiratory measures may be a better index of a specific ability, but it does not reflect the factors which are constituent parts. With respect to the individual factors, the index score has no diagnostic value. In order to know the functional status of the individual each factor must be considered individually. In constructing cardiovascular-respiratory tests, therefore, the <u>objective</u> must be stated. If one is interested in knowing the circulatory-respiratory status of the individual, all factors must be considered, with the sum of the scores, if desired, as yielding <u>additional</u> information. If one is interested in describing a particular ability, the items should be selected which significantly describe it, with a "weighted" sum prepared (regression equation).

CONCLUSIONS

1. A factor analysis of some selected cardiovascular-respiratory variables shows eight factors. These have been identified as:

   a. Pulse Pressure.
   b. Pulse Rate Response to Exercise in Relation to Normal.
   c. Pulse Rate Response to Exercise.
   d. Pulse Pressure in Response to Postural Change.
   e. Diastolic Pressure and Changes with Respect to Body Position.
   f. Respiratory Function.
   g. Blood Pressure Response to Changes in Position.
   h. Systolic Pressure.

Other factor analysis studies (not comparable with respect to specific factors) show a minimum of eight factors describing approximately the same selection of variables.

2. Utilizing the results of the factor analysis and in addition a logical analysis of the table of intercorrelations, the following variables were selected as being sufficiently unrelated as to be considered independent:

a. Horizontal Pulse Rate.
b. Difference between Horizontal and Standing Pulse Rates.
c. Difference between Normal Standing Pulse Rate and Pulse Rate two minutes after exercise.
d. Horizontal Systolic Pressure.
e. Difference between Horizontal and Standing Systolic Pressures.
f. Horizontal Diastolic Pressure.
g. Standing Diastolic Pressure.
h. Difference between Horizontal and Standing Diastolic Pressures.
i. Horizontal Pulse Pressure.
j. Difference between Horizontal and Standing Pulse Pressures.
k. Breath-holding 20 seconds after exercise.
l. Vital Capacity.
m. McCurdy-Larson Efficiency Test.

3. The implications of the factor analysis of the cardiovascular-respiratory variables and tests to test construction are: (a) the selection of the items for a complete evaluation should include all factors; (b) if some of the factors are to be eliminated, this must be done in terms of a specific criterion, which represents the use to be made of the selected factors; and (c) the sum of a number of variables may be a better index of a specific ability, but it does not reflect the factors which are constituent parts.

4. The eight factors isolated in this research are not described by any one of the ten test "index scores." The reasons for the lack of relationship are: (1) the factor may not be included in the battery, (2) the number of items in the battery may be so numerous that the influence of the factor is not reflected, (3) the system of scaling the items in the test batteries makes the same items incomparable, and (4) the test battery may yield information not included in the eight factors.

5. The Schneider and the McCurdy-Larson Tests are described to the extent of 67 percent and 64 percent respectively, by the eight isolated factors. The remaining eight tests are described from 80 to 100 percent. Additional physiological information, therefore, not given in the eight factors may be given by these tests. It was on the basis of validity evidence presented in other sources that the McCurdy-Larson Test [illegible] as part of the system of rating.

6. The Schneider[15] and the McCurdy-Larson Test[16] "Index Scores" are not described by the same factors. The index scores of these two tests are unrelated (.16).[17]

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[15] Schneider, E.C. A cardiovascular rating as a measure of physical fatigue and efficiency. J. Amer. Med. Assoc., 1920, 74, 1507-1510.

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[16] McCurdy, J.H. & Larson, L.A. The physiology of exercise. Philadelphia. Lea and Febiger. 1939, 316-336.

McCurdy, J.H. & Larson, L.A. The validity of circulatory-respiratory measures as an index of endurance conditions in swimming. Res. Quarter. of A.A.H.P.E.R., xi:3, Oct. 1940, 1-11.

McCurdy, J.H. & Larson, L.A. Age and organic efficiency. The Military Surgeon, 85:2, Aug. 1939, 93-103.

[17] The writer wishes to acknowledge help given by Mr. Herleik Quamme, Instructor in Tests and Measurements, in the statistical computations.

APPENDIX

Table I. Circulatory-Respiratory Variables used in Factor Analysis Studies by McCloy, Murphy, Quamme and Larson.

Tables II - IV. Results of Factor Analysis Studies by McCloy, Murphy, and Quamme.

Table I

Circulatory-Respiratory Variables Used in Factor Analysis Studies*

Variables**	McCloy College Men	Murphy College Women (age: 16-26)	Quamme College Men (age: 18-24)	Larson College Men (age: 18-24)
1. Hor. P.R.	x	x		x
2. Sit. P.R.		x	x	
3. Std. P.R.	x	x	x	x
4. Hor. S.P.	x	x		x
5. Sit. SP.		x	x	x
6. Std. S.P.	x	x	x	x
7. Hor. D.P.	x	x		x
8. Sit. D.P.		x	x	x
9. Std. D.P.	x	x	x	x
10. Hor. P.P.	x	x		x
11. Sit. P.P.		x	x	x
12. Std. P.P.	x	x	x	x
13. V.C.			x	x
14. B.H. 20 sec. aft. ex			x	x
15. P.R. 2 min aft ex (std)			x	x
16. Std. P.R. minus Hor. P.R.	x	x		x
17. Std. S.P. minus Hor. S.P.	x	x		x
18. Std. D.P. minus Hor. D.P.	x	x		x
19. Std. P.R. minus Hor. P.P.				x
20. . . . after consider Exp	x			
21. P.R. after Step Ex.		x		
22. P.R. 1 min after 15 Step Ex.		x		
23. P.R. 2 min after 15 Step Ex.		x		
24. P.R. 3 min after 15 Step Ex.		x		
25. P.R. after 35 Step Ex.		x		
26. P.R. 1 min after 35 Step Ex.		x		
27. P.R. 2 min after 35 Step Ex.		x		
28. P.R. 3 min after 35 Step Ex.		x		
29. Std. P.R. minus Sit. P.R.		x	x	
30. Std. B.P. minus Sit. S.P.		x	x	
31. Std. D.P. minus Sit. D.P.		x	x	
32. Std. P.P. minus Sit. P.P.			x	
33. Sit. P.R. minus Hor. P.R.		x		

Table I (Cont'd)

Variables	McCloy	Murphy	Quamme	Larson
34. Sit.S.P. minus Hor.S.P.		x		
35. Sit.D.P. minus Hor.D.P.		x		
36. P.R. after 15 Step Ex min.P.R.1 min after Ex.		x		
37. P.R. after 35 Step Ex min P.R.1 min aft Ex				
38. P.R. after 35 Step Ex min P.R.2 min aft Ex		x		
39. Tuttle Pulse Ratio Test (EH.Rating)			x	
40. Tuttle Pulse Ratio 1st (20 step ex)			x	
41. Tuttle 2nd Ratio (35 Step Ex)			x	
42. P.R. 1 min after Schneider Ex.	x			
43. P.R. std. 1 min aft Schneider Ex.	x			
44. Diff.Std.Nor.P.R. and P.R.2 min aft Ex.			x	x
45. McCloy Test				x
46. Barach Test				x
47. Stone Test				x
48. Basal Metabolic Test				x
49. P.P. x P.R.				x
50. P.P. x P.R. ≟				x
51. Crompton's Test				x
52. Schneider Test				x
53. McCurdy-Larson Test			x	x
54. Tigerstedt				x
Total Variables:	14	32	20	29

*The variables are listed in the four factor analysis studies to give information as to the bases for the factor determinations. It should be remembered, however, that the factor isolations are not entirely comparable, (1) because the variables in each of the four studies are not identical, and (2) because factor isolations and identification involves the judgment of the experimentor (see limitations).

**Hor. = horizontal
P.R. = pulse rate
S.P. = systolic pressure
Sit. = sitting
Std. = standing
D.P. = diastolic pressure
P.P. = pulse pressure
V.C. = vital capacity
B.H. = breath-holding 20 seconds after a standard exercise

Table II

McCloy Factor Analysis of Cardiovascular-Variables With Evidence for Identifications

Factor Identification	Variables used as a basis for factor identification with factor loadings (correlation with factor)	
	1. Rec.P.R.	.956
1. Heart Rates	2. P.R. one min after Schneider Ex.	.582
	3. P.R. after Schneider Ex.	.546
	4. Std.P.R.	.497
2. Effect of change of position on systolic pressure, especially reclining pressure	1. Std.Sys.Pressure minus Rec.S.P.	.899
	2. Rec.P.P.	.498
	3. Rec.S.P.	-.363
3. General Blood Pressure	1. Std. Dias. P.	.811
	2. Std. S.P.	.770
	3. Rec. Dias.P.	.716
	4. Rec. S.P.	.669
	1. Std. P.P.	.823
4. Pulse Pressures	2. Std. S.P.	.568
	3. Rec. P.P.	.525
	1. Std.Dias.P-Rec.D.P.	.817
5. Rec.Diastolic Pressures	2. Rec.Dias.P.	-.673
	3. Rec.P.P.	.452
6. Mech. governing return of heart rate to normal following exercise.	1. P.R. above std.Nor. 1 min, after ex.	.840
	2. P.R. 1 min after Schneider ex.	.635
	3. P.R. after Schneider ex.	.423
7. Secondary Mechanisms governing reclining systolic blood pressure	1. Rec. S.P.	.780
	2. Rec. P.P.	.536
	1. Std. P.R.	.722
8. Std. Heart Rate	2. Inc.P.R. from Rec. to Std.	.664

Table I

Murphy Factor Analysis of Cardiovascular Variables With Evidence for Identifications

Factor Identification	Variables Used as a Partial Basis for Factor Identification (Variables listed are those Used to Predict Each Factor)	
1. Mechanism governing rates of the heart beat.	1. Rec. Pulse Rate 2. Sit. Pulse Rate	.91 .89
2. Compensation mechanism that controls the return of pulse rates to normal after strenuous exercise	1. P.R. 1 min. after 35 Step Ex. 2. P.R. immed. after 35 Step Ex minus P.R. 2 min. after Ex.	.64 -.61
3. Emotional Accelaration which accompanies muscular effort	1. Pulse rate immediately after 15 steps minus P.R. 1 min. after ex.	.54
4. Mechanisms governing minute volume	1. Standing systolic pressure 2. Sitting pulse pressure	.84 .70
5. Mechanism controlling vasomotor tone of the vascular system	1. Reclining Diastolic pressure 2. Sitting Diastolic pressure	.84 .83
6. Mechanism governing the general splanchnic accommodations to changes of hydrostatic pressure due to changes of position	1. Std. Systolic minus reclining systolic 2. Std. Diastolic minus sitting diastolic	.77 .58
7. Redistribution mechanism of the blood upon change of position	1. Std. Systolic minus reclining systolic pressure 2. Rec. Diastolic pressure 3. Std. pulse pressure 4. Rec. systolic pressure	-.47 .35 -.46 .47
8. Redistribution mechanism governing planchnic relaxation in response to the raising of the hydrostatic pressure during muscular inactivity	1. Sitting pulse rate minus rec. pulse rate 2. Std. diastolic minus rec. diastolic pressure	.70 .40
9. Redistribution mechanism responding to changes in hydrostatic pressure in response to changes of position	1. Pulse rate immed. after 35 Step Ex. 2. Std. systolic minus sitting systolic pressure	.52 .52

Table IV

Quamme Factor Analysis of Cardiovascular--Respiratory Variables
With Evidence for Identifications

Factor Identification	Variables used as basis for factor identification and prediction, with factor loadings (correlation of variable with factor)	
1. Head or Maximum pressure	1. Sitting pulse pressure	.62
	2. Std. systolic pressure	.68
	3. Std. pulse pressure	.61
	4. Diff. Std.P.R. and P.R. 2 min after exercise	.53
2. Circulatory recovery to Exercise	1. Vital capacity	.44
	2. Std. pulse rate	.67
	3. Breath-holding after ex.	.45
	4. Pulse rate 2 min.after ex.	.60
3. Diastolic Response to Postural Changes	1. Std. diastolic pressure	.97
	2. Diff.Sit-Std diastolic pressure	.58
	3. Std. pulse pressure	-.65
4. Pulse Rate Acceleration to Exercise	1. Pulse ratio following 35 step ex.	-.66
	2. Pulse ratio following 20 step ex.	-.49
	3. Sitting pulse rate	.49
5. Diastolic Pressure	1. Sit. diastolic pressure	.73
	2. Diff. Sit-Std dias. "	-.48
	3. Diff.Sit-Std pulse "	.47
	4. Sitting pulse pressure	.44
6. The Return of Pulse Rate to Normal after Exercise	1. Std. pulse rate 2 min after exer.	.60
	2. Breath-holding 20 sec after exer.	.49
	3. Diff. Std P.R. and P.R. 2 min. after exer.	.49
7. Pulse Rate Response to Postural Changes	1. Std. pulse rate	.64
	2. Diff. Sit-Std P.R.	.54
	3. Sit Pulse Pressure	.32
8. Head or Maximum Pressure Response to Postural Changes	1. Diff. Sit-Std systol pressure	.68
	2. Sit systolic pressure	-.53
	3. Sit pulse pressure	-.40
	4. Diff. Sit-Std pulse pressure	.38