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# HUMAN VARIABLITY AND RESPIRATOR SIZING



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Anthropometry is discussed and data are given to assist in the designing and sizing of respirator facepieces. Racial, ethnic, and sexual differences in the measurements or proportions are discussed. A sizing and design concept and a research procedure are recommended with diagrams and descriptions of head and face measurements.

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# HUMAN VARIABILITY
# AND
# RESPIRATOR SIZING

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PREFACE

The work described in this report was conducted by the Anthropology Research Project, Webb Associates, Inc., under NIOSH contract HSM 99-73-15, "Anthropological Research Relating to the Sizing and Fit of Respirators."

The purpose of this report is to assist respirator facepiece designers in understanding human facial variation and to assist these designers in providing for this significant variation in the design of their products.

This report brings together in a single source existing anthropometry of the head and face and presents statistical concepts and technical guidelines for using these data in design and sizing of industrial respirators.

Dr. J. T. McConville acted as Principal Investigator for Webb Associates. Mr. Richard Lester and Mr. David Smith were Project Officers for the Engineering Branch, Division of Laboratories and Criteria Development, National Institute for Occupational Safety and Health.

We are grateful to Mr. C. E. Clauser and Mr. Milton Alexander, Human Engineering Operational Performance Branch, Aerospace Medical Research Laboratory, U. S. Air Force, for their permission to utilize the Anthropometric Data Bank in the analysis, and for their critical comments and review of the manuscript for Webb Associates.

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## ABSTRACT

Anthropometry, the study of human body size variability, should assume a vital role in respirator facepiece design. It would appear, however, that designers are either unaware of the available facial anthropometry or are unable to use these data effectively in the sizing and design of respirator facepieces.

This report was developed to assist designers in understanding the sources of human facial variability, quantifying that variability and describing a design concept to effectively use the existing data in sizing of respirator facepieces. Appendixes to the report detail the equipment and methods used in measurements of the head and face.

# INTRODUCTION

Of central importance to the anthropologist is understanding the nature and significance of man's physical and cultural variation. Physical anthropologists have long directed their attention to the determination of human physical variability and its meaning in terms of evolution and race, growth and development, and in environmental adaptation. It has only been in more recent times, particularly during and since World War II, that the study of human variability with respect to the design of clothing, personal protective equipment and work station layout has received comparable emphasis.

While a considerable body of anthropometric data is available today, it is often apparent that designers are unaware of its existence or find it so packed with diverse information as to obscure what is needed for their particular purpose.

The purpose of this report is, therefore, to bring together in a single source the pertinent anthropometry of the head and face in summary form; specifically, to arrange it for maximum utility and develop in some detail the statistical concepts of treating human variability in the design and sizing of industrial respirators.

## Section I

## HUMAN MORPHOLOGIC VARIABILITY

One has only to view a group of people to be struck by the range of diversity in the size and shape of the animal man. This diversity, often a pleasure for visual esthetics, can be a source of annoyance from the standpoint of design. For those involved in design problems, the human body has an outstanding number of irregularly curved surfaces, assorted angular projections and an assortment of appendages, all of which tend to compound a straightforward design solution. All in all, taken individually or collectively, man lacks the proper degree of reproductive quality control to make a satisfactory design subject.

Despite the quality of the subject material, the designer of respirators must arrive at a design solution which will be adequate to cope with the irregularities of size and shape of the head and face of potential users. It would be of value to the designers, therefore, to have a detailed quantification of head and facial variability. Prior to attempting to quantify this variability, we may first discuss briefly the source of this diversity.

Man, individually and collectively, is a manifestation, in shape and size, of his genetic heritage. This manifestation of the genetic potential can, however, be modified by external factors such as nutrition, disease, and trauma. We can, in a general fashion, classify the total human morphological variability into two broad categories of intra- and inter-individual variability. The former is, of course, that variability which occurs in the individual through secular time as a function primarily of growth, maturity and senescence. Intra-individual variability is generally of a minor nature for the mature individual with the major changes occurring prior to physical maturity during the principal linear growth phases and during old age. It should be noted, however, that the individual is not in a morphologically steady state after the cessation of the linear growth. During maturity, among Americans, there is often an increase in body weight with an accompanying increase in the associated body girths. This change is, of course, less of a factor for measures of the head and face than in the other parts of the body. There is, in addition, evidence for some increases in facial and cranial dimensions after the period when linear body growth has ceased. Israel (1971), using serial roentgenograms, has documented head and face dimensional increases that continue throughout adult life. These changes are, however, of sufficiently small magnitude (1 to 2%) as to be essentially ignored. As our principal concern is with the morphological variability among the working population, ages 18 to 65, we may, in general, ignore the effects of intra-individual variation associated with growth and aging.

In terms of our specific requirements for understanding human morphological variability, the inter-individual differences are of major concern. The differences between the sexes are a principal source of such variability with the female having, in general, a smaller overall head and face with far less pronounced or rugged features. A second source of such variability is associated with ethnic and racial origins. While all of living man belongs to a single biological species, he is, like other life forms, not geographically uniform but differentiated into a number of local variants or breeding groups. These variants often differ in a number of morphological traits such as skin, eye and hair color, nose size and shape, etc. with a particular trait being highly characteristic for a single strain. It is not our intent to probe for the reasons behind these morphological differences between variants of man but only to acknowledge their existence and attempt to deal with them in terms of sizing and design requirements. This is of some importance to us because of the many ethnic and racial groups that constitute the American population.

In biological populations, most morphological traits, particularly of size and shape, are continuous rather than discrete and are distributed normally. The latter implies that the frequency of measured values for any particular trait approximates the bell shaped distribution curve as illustrated below.

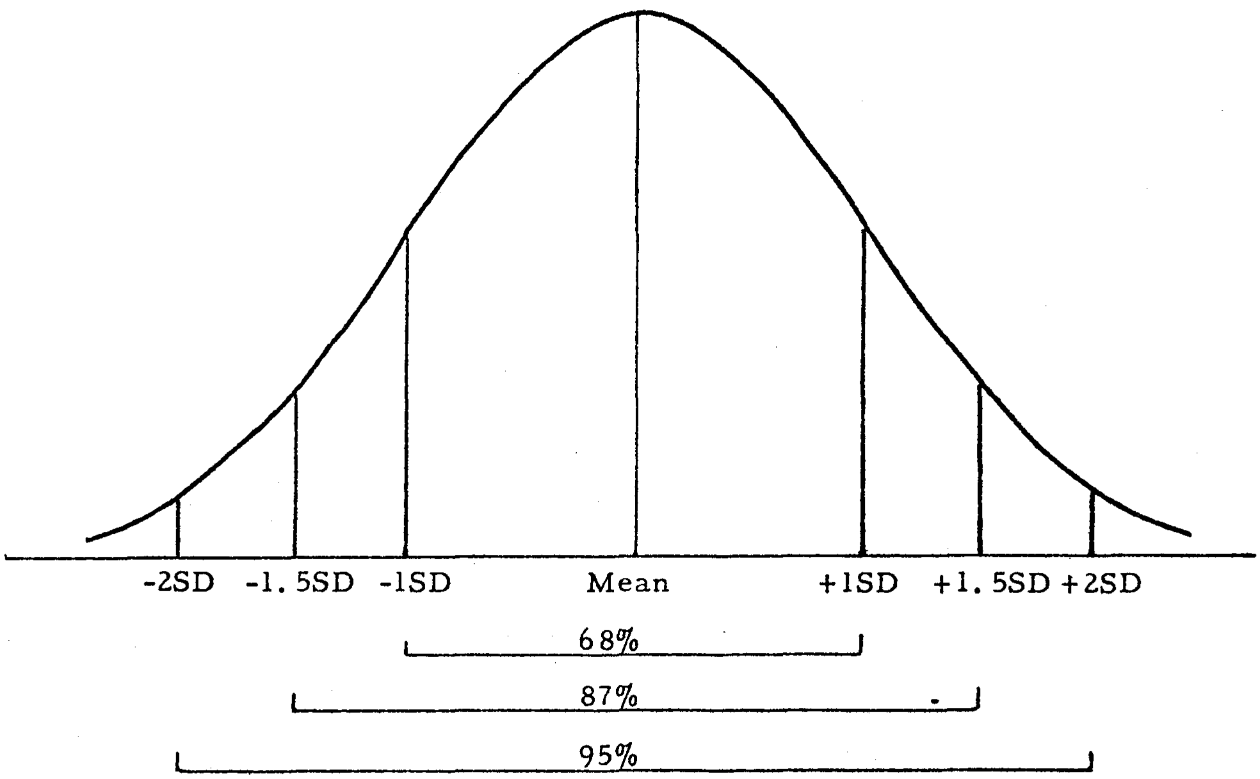


Figure 1. The Normal Curve

The majority of the values for a particular dimension tend to cluster around the center or mean value and are less frequent toward the ends of the curve. The statistic, standard deviation (SD), describes the variation in the distribution about the mean value with ∿68% of the measured values within the limits of the mean ± 1 SD, 87% within the mean ± 1.5 SD, etc. The width of the curve approximates the range of variability for a particular dimension from smallest to largest and the height of the curve the anticipated frequency for any particular measured value. The two extreme tails of the distribution contain those individuals who are most dissimilar from the majority of the population for that particular trait. These individuals may be clinically normal but exceptional in size and shape; for example, the professional basketball players, the Olympic weight-lifters, the professional jockeys.

We have, in addition, in our population individuals who suffer from malnutrition or diseases such as pituitary dwarfism, acromegalia, etc. These individuals may exist in the active working population but will not, in all probability, be considered in any design problem as their numerical infrequency and placement at the far ends of the distribution for a morphological trait almost assures their being disregarded in a design solution. Indeed, even if a concerted effort were to be made to accommodate these individuals, it would undoubtedly prove to be impossible as they are often unique in size or shape and require special consideration.

While it is possible to disregard the intra-individual variation in the sizing and design of respirators for the working population, it is obvious that inter-individual variation must be considered and must be effectively accommodated if a respirator is to be successful for a wide variety of potential users.

With some knowledge as to the source of morphological variation, we may now attempt to quantify this variability in some usable fashion. We must, therefore, ascertain a source of such head and face anthropometry for analysis.

The majority of the American anthropometric data are from four primary sources: a) growth surveys; b) anthropometric surveys of students; c) health and occupational surveys; and d) military anthropometric surveys.

(a) The anthropometric data from the various growth surveys are of very limited value for our particular purpose. In general, these data are obtained from intensive longitudinal studies of small regional samples and do not include comprehensive measurements of the head and face. The studies are quite naturally concentrated on the early growth years with little usable anthropometric data for the post adolescent ages being gathered.

(b) A number of anthropometric studies have been made of various student populations. Those made on college students are typically oriented toward entering freshmen (17-19 years of age), include a relatively few body dimensions and are in most instances a generation or so out of date.

(c) The anthropometry of occupational groups, particularly groups drawn from industrial or consumer populations, would be most useful. It is unfortunate that the relatively few studies of this nature conducted in the United States consider a very limited number of body dimensions and these are usually very specifically related to workspace layout. None of the studies available included any head and face measures that would be representative, in even suggestive form, of the broad civilian working populations.

(d) The remaining source of anthropometric data is that of surveys of military populations. This source of data is particularly rich and current with each of the United States military services completing a major anthropometric survey of its members within the last ten years. A listing of a number of post World War II anthropometric surveys of military personnel is compiled in table form below.

Table 1

Major Anthropometric Surveys of U. S. Military Populations*

| Date of Survey and Sample | Sample Size | Number of Measured Variables | Number of Head & Face Variables | Age of Sample $\bar{X}$ (SD) |
|---|---|---|---|---|
| 1946 Army Men | >25,000 | 65 | 11 | ∿24 |
| 1946 Army Women | > 8,500 | 50 | 9 | 26,6(5.4) |
| 1950 Air Force Fliers | > 4,000 | 132 | 33 | 27.4(4.2) |
| 1953 Air Force Women | 841 | 63 | 6 | 19.8(2.7) |
| 1953 Air Force Basics | > 3,000 | 60 | 6 | 18.9(1.9) |
| 1964 Navy Fliers | 1,549 | 97 | 32 | ∿28 |
| 1965 Air Force Males | 3,869 | 156 | 42 | 22.7(6.5) |
| 1966 Army Males | 6,682 | 70 | 12 | 22.2(4.6) |
| 1966 Navy Males | 4,095 | 70 | 12 | 19.9(1.5) |
| 1966 Marine Males | 2,008 | 70 | 12 | 20.9(2.9) |
| 1967 Air Force Fliers | 2,420 | 188 | 46 | 30.0(6.3) |
| 1968 Air Force Women | 1,905 | 137 | 27 | 22.9(6.5) |
| 1970 Army Fliers | 1,482 | 85 | 15 | 26.2(5.5) |

* Post WW II

In these military surveys we find a wealth of head and face anthropometric data immediately available for use. The question of the appropriateness of using the military anthropometry as design data for civilian workers has been discussed in considerable detail in a previous study (McConville et al., 1972). From this study it was our conclusion that the head and face anthropometric data from military surveys could be used with a high degree of confidence to establish respirator design criteria for the civilian working population.

In Table 2 the summary statistics are given for the measurements of the head and face that are available from the principal military surveys conducted since World War II. These are the data that we will utilize to examine and quantify the morphological variability of the head and face. The data are from each of the military services (columns I - XI) and include as many as forty-seven head and face variables (variables 1 - 47) as well as the variables of age, height and weight (variables 48, 49, 50).* Each of the surveys represents, in a fashion, a somewhat different segment of the American population. The 1946 Army Male Survey (IV), for example, was a composite group of Army men and had in common only that they were being processed for discharge from the Army at one of several separation centers.

* A brief general description of the measuring techniques used is given in Appendix B. For a more comprehensive discussion of the measuring techniques used in the different surveys, see Garrett, J. W. and K. W. Kennedy, 1971.

Table 2

Head and Face Anthropometry from Selected Military Surveys - Mean (S.D.)*

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable Name | 1967 USAF n=2420 | 1965 USAF n-3869 | 1950 USAF n=4000 | 1946 Army n=~25,000 | 1966 Army n=6682 | 1970 Army n=1482 | 1964 Navy n=1549 | 1966 Navy n=4095 | 1966 Marines n=2008 | 1946 Army Women n=~8500 | 1968 USAF Women n=1905 |
| 1 Head Circ | 57.52 (1.43) | 56.26 (1.65) | 57.03 (1.53) | 56.65 (1.58) | 56.11 (1.61) | 56.32 (1.54) | 57.54 (1.40) | 55.94 (1.56) | 56.13 (1.54) | 55.16 (1.56) | 54.87 (1.62) |
| 2 Sagittal Arc | 34.64 (1.66) | 37.85 (1.53) | 38.11 (1.52) | | | 35.88 (1.44) | 36.91 (2.18) | | | | 34.79 (1.49) |
| 3 Min Frontal Arc | 13.60 (0.79) | 11.97 (0.88) | 13.67 (0.96) | | | | | | | | |
| 4 Bit-Coronal Arc | 35.76 (1.26) | 35.08 (1.39) | 35.05 (1.24) | | | 35.51 (1.23) | 35.52 (1.32) | | | | 33.92 (1.40) |
| 5 Bit-Min Front Arc | 30.81 (1.00) | 30.48 (1.11) | 30.48 (1.05) | | | | 30.20 (1.08) | | | | |
| 6 Bit-Subnasal Arc | 29.31 (1.02) | 28.70 (1.17) | 28.98 (1.07) | | | | 28.68 (1.06) | | | | |
| 7 Bit-Menton Arc | 32.65 (1.24) | 31.41 (1.44) | 32.33 (1.23) | | | | 32.21 (1.27) | | | | |
| 8 Bit-Submandibular | 30.98 (1.58) | 29.29 (1.67) | 30.62 (1.54) | | | | 31.22 (1.42) | | | | |
| 9 Bit-Posterior Arc | 29.45 (1.49) | | 29.37 (1.34) | | | | 31.44 (2.09) | | | | |
| 10 Head Length | 19.87 (0.67) | 19.62 (0.72) | 19.70 (0.64) | 19.47 (0.70) | 19.47 (0.73) | 19.70 (0.67) | 19.83 (0.66) | 19.42 (0.72) | 19.43 (0.72) | 18.37 (0.65) | 18.41 (0.68) |
| 11 Nasal Root Breadth | | | 1.56 (0.21) | 1.42 (0.23) | | | 1.85 (0.30) | | | 1.55 (0.24) | |
| 12 Ear Breadth | 3.80 (0.30) | 3.52 (0.33) | 3.66 (0.27) | | | | 3.57 (0.33) | | | | 2.98 (0.33) |
| 13 Ear Length | 6.60 (0.43) | 6.34 (0.46) | 6.27 (0.41) | | | | 6.53 (0.40) | | | | 5.24 (0.44) |
| 14 Ear Lth above Tragion | 2.94 (0.29) | 2.87 (0.30) | 2.97 (0.28) | | | | | | | | |
| 15 Head Breadth | 15.60 (0.54) | 15.31 (0.58) | 15.41 (0.51) | 15.21 (0.59) | 15.27 (0.59) | 15.27 (0.54) | 15.57 (0.53) | 15.23 (0.57) | 15.28 (0.57) | 14.57 (0.55) | 14.52 (0.59) |
| 16 Max Frontal Br | 11.60 (0.46) | 11.46 (0.48) | 11.96 (0.50) | | | | 12.26 (0.72) | | | | |
| 17 Bitragion Br | 14.25 (0.56) | 13.83 (0.65) | 14.22 (0.53) | | 13.50 (0.56) | 14.17 (0.57) | 13.99 (0.52) | 13.38 (0.53) | 13.46 (0.55) | | 12.89 (0.50) |
| 18 Face Breadth | 14.23 (0.52) | 13.99 (0.56) | 14.09 (0.50) | 13.90 (0.60) | 13.99 (0.56) | 13.87 (0.53) | 13.62 (0.71) | 13.94 (0.55) | 13.97 (0.54) | 13.08 (0.54) | 12.90 (0.58) |
| 19 Bigonial Br | 11.73 (0.69) | 10.72 (0.54) | 10.86 (0.55) | 10.76 (0.60) | | | 11.91 (0.85) | | | | 10.19 (0.56) |
| 20 Ear to Ear Br | 18.83 (0.81) | 18.43 (0.93) | | | | | | | | | 15.83 (0.95) |
| 21 Biocular Br | 9.17 (0.49) | 9.42 (0.53) | 9.59 (0.44) | 9.22 (0.51) | | | 9.43 (0.41) | | | 9.02 (0.46) | 9.67 (0.49) |
| 22 Interpupillary Br | 6.27 (0.36) | 6.23 (0.39) | 6.33 (0.36) | | 6.13 (0.40) | 5.91 (0.36) | 6.51 (0.28) | 6.11 (0.33) | 6.08 (0.39) | | |
| 23 Interocular Br | 3.33 (0.28) | 3.15 (0.28) | 3.17 (0.25) | 3.24 (0.31) | | | 3.21 (0.29) | | | | |
| 24 Nose Breadth | 3.54 (0.29) | 3.42 (0.38) | 3.33 (0.26) | 3.37 (0.29) | | | 3.54 (0.26) | | | 3.10 (0.26) | 3.19 (0.33) |
| 25 Lip Length | 5.23 (0.37) | 4.87 (0.44) | 5.16 (0.36) | | | | 5.14 (0.43) | | | | 4.38 (0.42) |
| 26 Ear Protrusion | 2.16 (0.34) | 2.11 (0.37) | 2.15 (0.36) | | | | 2.19 (0.35) | | | | |
| 27 Subnasale-Nasal Rt L | 5.13 (0.37) | 5.10 (0.37) | 5.09 (0.34) | 5.53 (0.50) | | | 5.34 (0.37) | | | 4.77 (0.45) | 4.55 (0.41) |
| 28 Philtrum | 1.55 (0.28) | 1.47 (0.26) | 1.94 (0.34) | | | | | | | | |
| 29 Lip to Lip Length | 1.73 (0.38) | 1.86 (0.40) | 1.62 (0.31) | | | | 1.66 (0.36) | | | | |
| 30 Menton-Subnasale L | 6.90 (0.53) | 7.01 (0.61) | 6.67 (0.69) | | | | 7.02 (0.59) | | | | 5.54 (0.51) |
| 31 Face Length | 12.03 (0.61) | 11.92 (0.68) | | | 12.03 (0.66) | 11.33 (0.67) | | 11.95 (0.60) | 12.02 (0.65) | | 10.63 (0.61) |
| 32 Glabella-Vertex | 9.27 (0.97) | 9.21 (0.81) | | | | 8.65 (0.93) | | | | | |
| 33 Nasal Rt-Vertex | 10.75 (0.94) | 10.84 (0.78) | | | | | | | | | |
| 34 X-Canthus-Vertex | 11.95 (0.77) | | | | | | | | | | 11.76 (0.92) |
| 35 Pronasale-Vertex | 14.74 (1.10) | 14.83 (0.87) | | | | | | | | | 14.76 (1.17) |
| 36 Subnasale-Vertex | 16.09 (1.02) | | | | | | | | | | 15.91 (1.10) |
| 37 Stomion-Vertex | 18.37 (1.00) | 18.23 (0.84) | | | | | | | | | 17.83 (1.12) |
| 38 Menton-Vertex | 22.77 (1.02) | 22.67 (0.97) | | | | | 22.18 (1.02) | | | | 21.91 (1.14) |
| 39 Tragion-Vertex | 13.45 (0.61) | | 12.97 (0.75) | 13.11 (0.60) | 13.23 (0.79) | 13.29 (0.58) | 13.11 (0.64) | 13.54 (0.85) | 13.38 (0.68) | 13.17 (0.90) | 12.73 (0.76) |
| 40 Glabella to Wall | 20.35 (0.67) | 19.83 (0.71) | | | | | | | | | |
| 41 Nasal Rt to Wall | 20.17 (0.66) | 19.60 (0.70) | 19.69 (0.86) | | 19.10 (0.72) | 19.98 (0.68) | 20.04 (0.69) | 19.04 (0.71) | 19.08 (0.72) | | |
| 42 X-Canthus to Wall | 17.79 (0.66) | 17.21 (0.74) | 17.21 (0.79) | | 17.24 (0.98) | 17.30 (0.72) | 17.78 (0.70) | 17.19 (1.06) | 17.34 (0.97) | | 16.37 (0.97) |
| 43 Pronasale to Wall | 22.68 (0.75) | 21.98 (0.82) | | | 22.19 (0.83) | 22.67 (0.79) | 22.85 (0.76) | 22.05 (0.80) | 22.14 (0.81) | | 21.19 (0.96) |
| 44 Subnasale to Wall | 20.99 (0.79) | 20.55 (0.91) | | | | | | | | | 19.66 (0.98) |
| 45 Lip Prom to Wall | 21.16 (0.86) | | | | | | | | | | 19.30 (1.06) |
| 46 Chin Prom to Wall | 20.47 (1.05) | | | | | | | | | | 18.23 (1.14) |
| 47 Tragion to Wall | 10.33 (0.65) | 9.63 (0.68) | 10.23 (0.75) | | 10.28 (1.19) | 10.33 (0.69) | 10.81 (0.76) | 10.46 (1.34) | 10.45 (1.21) | | 10.17 (0.90) |
| 48 Age | 30.03 (6.31) | 22.69 (6.49) | 27.39 (4.22) | ~24 | 22.17 (4.64) | 26.21 (5.51) | | 19.86 (1.47) | 20.88 (2.87) | 26.63 (5.42) | 22.93 (6.45) |
| 49 Height | 177.34 (6.19) | 175.28 (6.56) | 175.56 (6.16) | 173.91 (6.39) | 174.52 (6.61) | 174.56 (6.33) | 177.64 (5.91) | 175.33 (6.53) | 174.56 (6.31) | 162.36 (6.16) | 162.10 (6.00) |
| 50 Weight | 173.60 (21.44) | 156.49 (23.92) | 163.44 (20.82) | 154.81 (20.56) | 159.09 (23.36) | 170.79 (23.79) | 171.40 (19.09) | 157.75 (23.28) | 160.16 (19.67) | 131.87 (19.97) | 127.28 (16.60) |

* Age in years, weight in pounds, all other dimensions in centimeters.

The Army Women's Survey (X) was similarly a composite made up of officer and enlisted personnel of the Women's Army Corps, Nurses, etc., being separated from active duty in 1946. The very heavy manpower demands made by the services during World War II necessitated the relaxing of physical standards normally maintained by the military establishments so that the 1946 U. S. Army male and female samples were, in all probability, broadly representative in body size of their age groups in the civilian working population at the time of the survey.

The 1967 Air Force fliers sample (I) is composed largely of rated fliers; that is, officers on flying duty. This sample is characterized by individuals drawn from the upper socio-economic levels of our society with a relatively high educational level and better than average physical condition. Similar selection criteria are characteristic of the 1950 Air Force fliers (III) and 1964 Navy fliers (VII) and to a lesser degree the 1970 Army fliers (VI). The latter sample is primarily composed of officer and warrant officer helicopter pilots, and warrant officer candidates undergoing helicopter flight training.

The 1965 U. S. Air Force sample (II) is predominantly but not exclusively composed of airmen undergoing basic training. The 1966 Army (V), Navy (VIII), and Marine (IX) samples are also predominantly, but not exclusively, recruits measured during basic or advanced training.

The 1967 U. S. Air Force survey is listed to the left as it was the most complete in terms of the number of variables considered. The other surveys were searched for variables which could be considered comparable to the USAF 1967 dimensions and these were then listed for comparison. In one case, a variable of some interest to us, Variable #11, Nasal Root Breadth, was not measured in the USAF 1967 survey but was measured previously and this was then included in the final listing of variables.

We must be aware of the fact that these body surveys of the various military populations were conducted over a period of approximately twenty-five years, were conducted by different individuals, often for different purposes, and with some diversity in the interpretations of the landmarks and techniques of measurement. Comparisons between surveys are often somewhat tenuous for these reasons with the best comparisons being those of subjects who constitute subsets of a particular survey.

The comparability of the listing was determined by comparison of the measurement descriptions from the various surveys. As a number of the surveys listed here have not been published, we have worked from the notes made available to us by the principal investigator in charge of the survey. Some inconsistencies may still exist in these data; that is, measures from different surveys that are listed as comparable may not be equated due to differences in interpretation of anthropometric landmarks and the like. It is of considerable interest to note, however, that when well established landmarks are used for a particular measurement (e.g., tragion), differences among the various surveys become quite small.

In attempting to evaluate the differences in head and face size between sexes, we are forced to use data from different surveys. We have available, for example, the U. S. Army surveys of 1946 for males (IV) and females (X), as well as the more recent comparison of USAF males (I) and females (XI). A cursory examination of these data indicates the female samples show, in general, a pattern of lower values for the dimensions measured. Indeed, it has often been a stated rule of usage that the female body measurements average about 92% of comparable male measurements. In addition to the difference in size, the female head and face has been described as usually more rounded and relatively more gracile so that in sexing a skull the initial impression of descriptive features, rather than size per se, is often the deciding factor (Krogman, 1962).

Based upon the available data for analysis, we arrived at the following ratios of female/male size:

Table 3

Ratios of Male/Female Size

| | WAF/USAF | USA FEMALES/MALES |
|---|---|---|
| Head Circ | 95.4% | 97.4% |
| Head Lgth | 92.7 | 94.4 |
| Head Breadth | 93.1 | 95.8 |
| Face Lgth | 88.4 | |
| Upper Face Lgth | 88.7 | 86.3 |
| Face Breadth | 90.7 | 94.1 |
| Nose Breadth | 90.1 | 92.0 |
| Average of Above | 91.3 | 93.3 |

It would appear that an average of 92% would not be an unreasonable average value for the ratio of female to male head and face dimensions.

The use of an average, however, does not give us a complete picture of the distribution of measured values. In Figures 2 - 4 are illustrated the bivariate frequency distributions for USAF 1967 and WAF 1968 data presented as 95% ellipses of selected head and face dimensions.[1] It is apparent from these illustrations that while the mean values for the male and female data are often quite different, the degree of overlap in the two distributions range from approximately 20 to 50%. This would imply that we have essentially a continuity of size ranging from the smallest female to the largest male with a good degree of overlap of the larger female faces and the smaller male faces.

It would be of practical importance in respirator sizing and design if one could assume that a male face of a given size, based upon any selective dimensions, equates with a female face of the same size and the reverse. This assumption would not appear unreasonable but does require some level of validation if it is to be widely used with confidence. We have conducted analysis of the existing data toward the evaluation of this assumption but without success. We are unable at this time, with the existing facial anthropometry, to prove or disprove this assumption.

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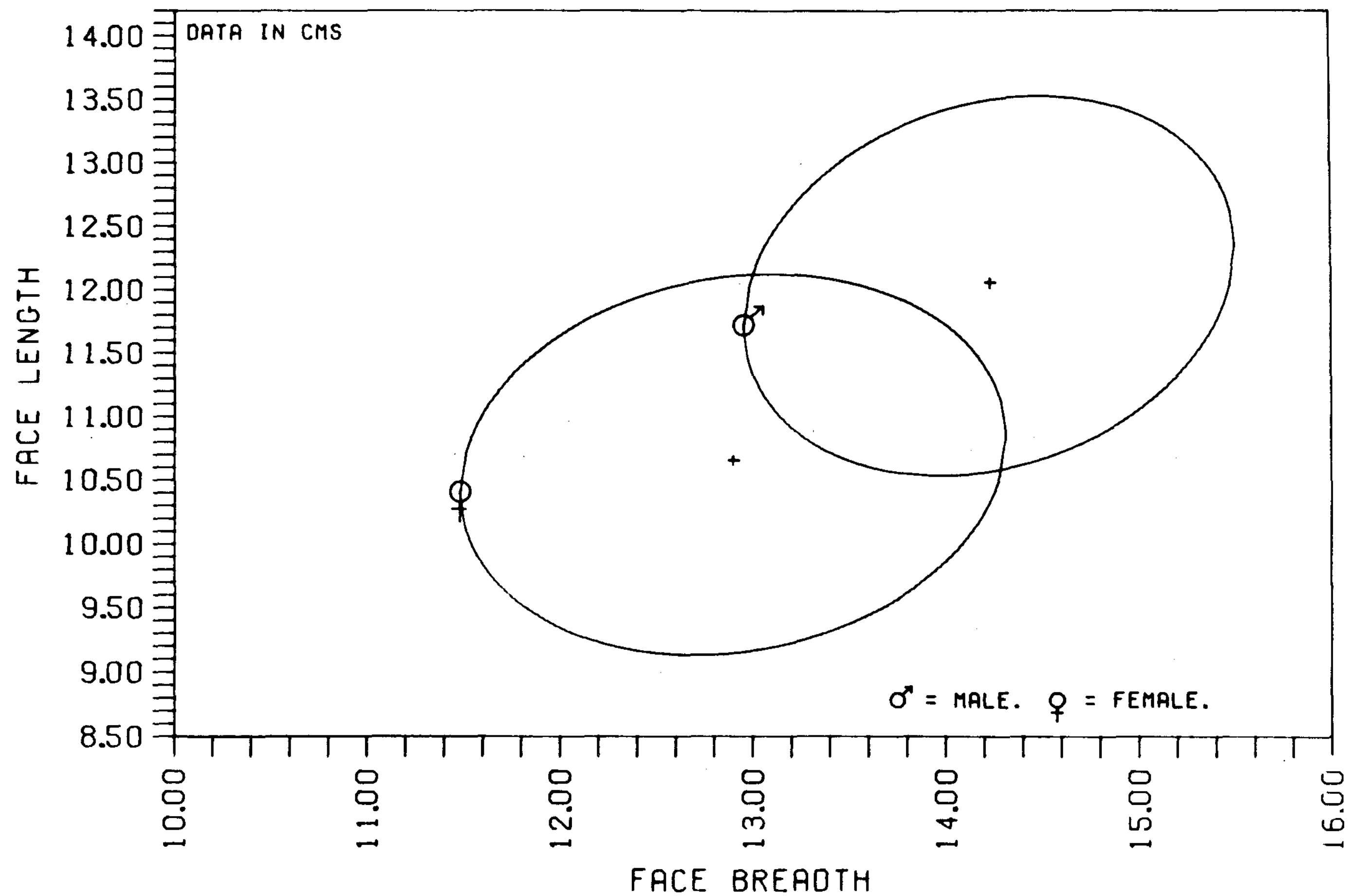
1 The 95% ellipse is a simplified form of a bivariate scattergram with the circumference of the ellipse encompassing the central 95% of the distribution of points.

Figure 2

Male and Female Bivariate Tables*

FACE BREADTH-FACE LENGTH ELLIPSES --- P = 95%

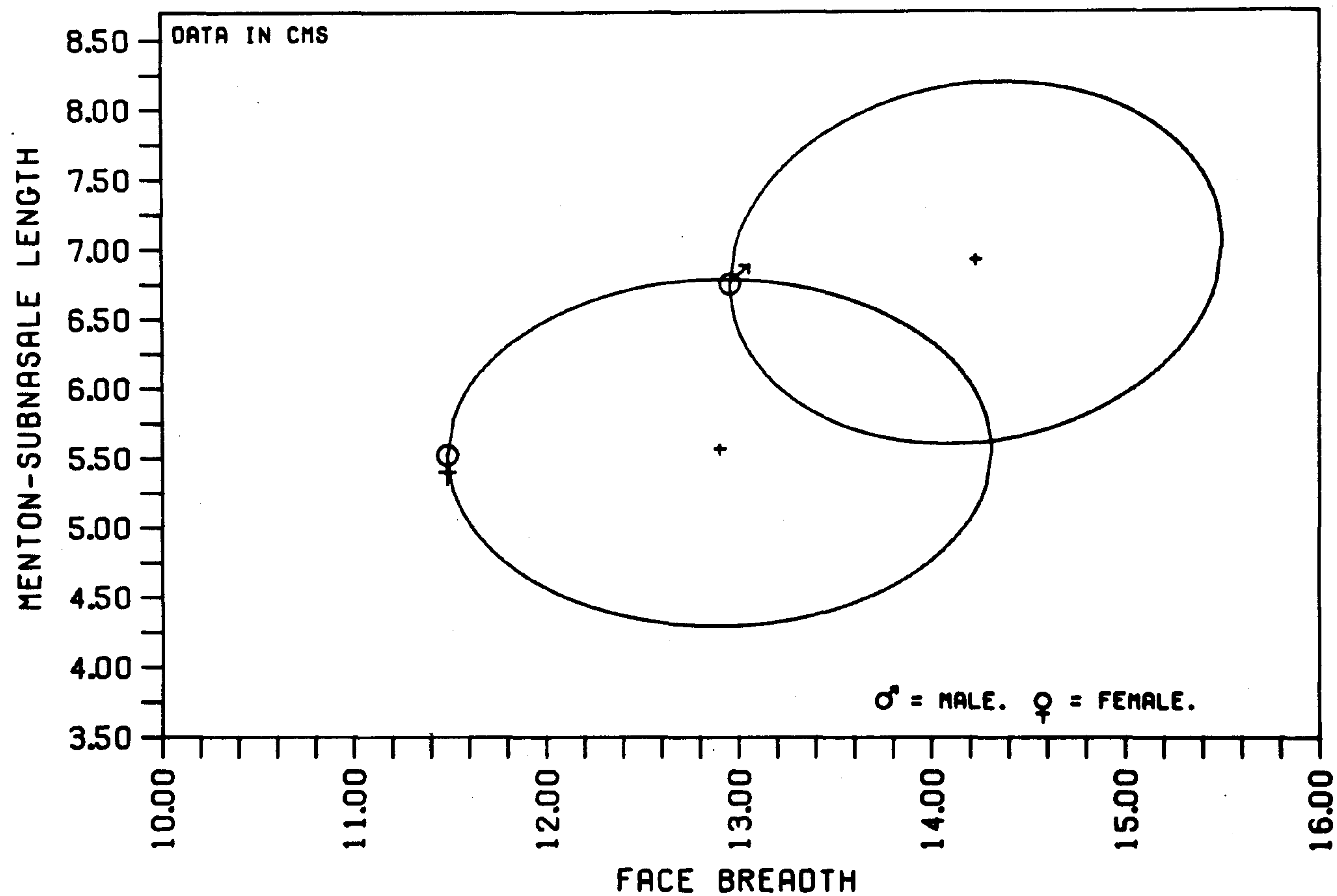



* In Centimeters

Figure 3

Male and Female Bivariate Tables*

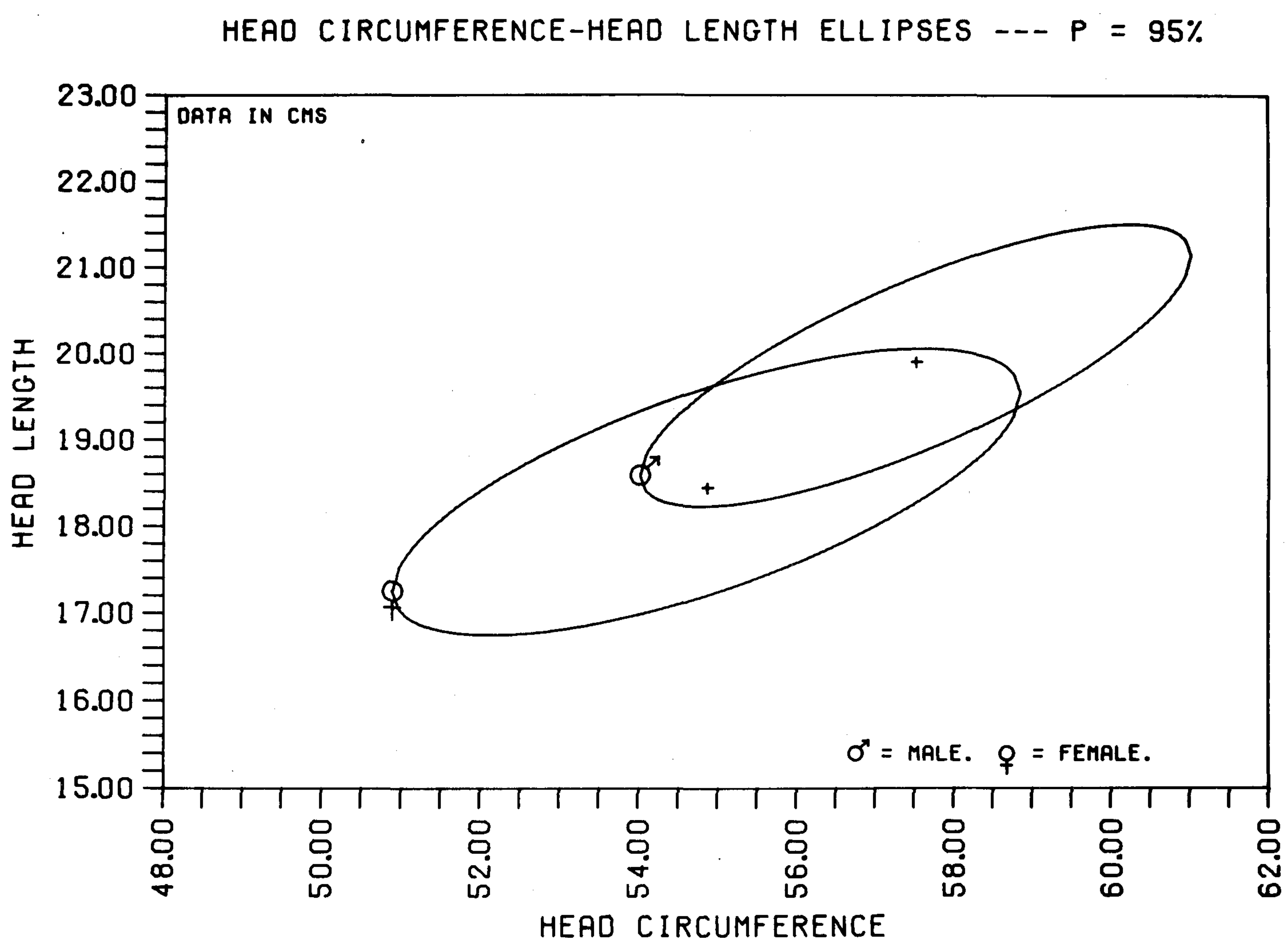
FACE BREADTH-MENTON SUBNASALE LENGTH ELLIPSES --- P = 95%




* In Centimeters

Figure 4

Male and Female Bivariate Tables*




* In Centimeters

The question also arises as to whether the measurements exhibit essentially the same relationship for the male and female face irrespective of overall size. We can investigate this by computing a matrix of head and face correlation coefficients for comparable male and female measurements and plot these on a graph. In this exercise the male correlation coefficient is used as the y or ordinate value and the female coefficient as the x or abscissa value. If a very high degree of relationship exists between the male and female head and face measurements, then the points on the graph will approximate a straight line that passes through the origin of the graph and bisects the first and third quadrant. A plot of some 406 data points, using the USAF 1967 and WAF 1968 correlation coefficients, indicated that the relationships of the female head and facial measurements were indeed quite similar to those relationships for comparable measurements from the male series.

Morphological head and face variability relating to ethnic/racial origins is of considerable interest because of the broad distribution in origins of the American population. In the 1970 U. S. Census the racial and ethnic origins of the U. S. population by specific categories were obtained. A portion of the information is shown in Table 4 on the following page. These data are not as comprehensive as might be desired but do indicate the racial/ethnic variability in the population that must be considered in respirator sizing and design.

Table 4

Racial/Ethnic Origins of U. S. Population*

| Group | Number in Thousands | Percent |
|---|---|---|
| White | 177,784 | 87.5 |
| Spanish Speaking | 10,115 | 4.9 |
| Black | 22,580 | 11.1 |
| Other | 2,883 | 1.4 |
| Indian | 793 | 0.4 |
| Japanese | 591 | 0.3 |
| Chinese | 435 | 0.2 |
| Filipino | 343 | 0.2 |
| Other | 720 | 0.4 |

* Source: Bureau of Census, April 1970

The military anthropometric surveys are particularly useful in examining the differences among the various racial and ethnic groups that exist in the U. S. population. In these surveys we have anthropometric data on relatively large numbers of individuals, drawn from all regions of the country and all classes, who appear in a random order throughout the survey.

In our initial analysis we have used the USAF 1965 survey for American male White-Black comparisons. This comparison is tabulated in Table 5 (page 19) and consists of an age sample of 343 Whites and Blacks matched on the basis of chronological age. The table presents the actual values for the mean and the standard deviation (in brackets), as well as the difference (Δ) White-Black and the ratio Black/White x 100. It will be noted that the majority of the differences are relatively insignificant

Table 5

Comparison of Head and Face Measurements - Mean (SD)*
White and Black (Male)

Matched Sample: Age n = 343

| | | White | | Black | | ΔW-B | %B/W |
|---|---|---|---|---|---|---|---|
| 1. | Head Circ | 55.77 | (1.64) | 56.17 | (1.59) | -.40 | 100.72 |
| 2. | Sagittal Arc | 37.59 | (1.41) | 37.55 | (1.53) | .04 | 99.89 |
| 3. | Min Frontal Arc | 11.80 | (0.87) | 11.89 | (0.83) | -.09 | 100.76 |
| 4. | Bit-Coronal Arc | 34.77 | (1.30) | 34.61 | (1.31) | .16 | 99.54 |
| 5. | Bit-Min Front Arc | 30.28 | (1.12) | 30.45 | (1.10) | -.17 | 100.56 |
| 6. | Bit-Subnasal Arc | 28.30 | (1.07) | 29.09 | (1.10) | -.79 | 102.79 |
| 7. | Bit-Menton Arc | 30.87 | (1.37) | 31.55 | (1.35) | -.68 | 102.50 |
| 8. | Bit-Submandibular | 28.63 | (1.46) | 28.79 | (1.49) | -.16 | 100.56 |
| 9. | Bit-Posterior Arc | 24.93 | (1.23) | 24.84 | (1.12) | .09 | 99.64 |
| 10. | Head Length | 19.53 | (0.72) | 19.78 | (0.69) | -.25 | 101.28 |
| 11. | Nasal Root Breadth | 1.78 | (0.23) | 1.99 | (0.29) | -.21 | 111.80 |
| 12. | Ear Breadth | 3.46 | (0.33) | 3.44 | (0.32) | .02 | 99.42 |
| 13. | Ear Length | 6.25 | (0.39) | 5.97 | (0.41) | .28 | 95.52 |
| 14. | Ear Lth above Tragion | 2.81 | (0.29) | 2.70 | (0.31) | .11 | 96.09 |
| 15. | Head Breadth | 15.14 | (0.59) | 15.08 | (0.54) | .06 | 99.60 |
| 16. | Max Frontal Br | 11.41 | (0.49) | 11.52 | (0.51) | -.11 | 100.96 |
| 17. | Bitragion Br | 13.63 | (0.61) | 13.56 | (0.56) | .07 | 99.49 |
| 18. | Face Breadth | 13.84 | (0.57) | 13.86 | (0.52) | -.02 | 100.14 |
| 19. | Bigonial Br | 10.61 | (0.50) | 10.50 | (0.51) | .11 | 98.96 |
| 20. | Ear to Ear Br | 18.39 | (0.92) | 17.52 | (0.80) | .87 | 95.27 |
| 21. | Biocular Br | 9.17 | (0.46) | 9.69 | (0.46) | -.52 | 105.67 |
| 22. | Interpupillary Br | 6.09 | (0.36) | 6.45 | (0.38) | -.36 | 105.91 |
| 23. | Interocular Br | 3.12 | (0.24) | 3.34 | (0.29) | -.22 | 107.05 |
| 24. | Nose Breadth | 3.24 | (0.24) | 4.06 | (0.34) | -.82 | 125.30 |
| 25. | Nose Protrusion | 2.29 | (0.27) | 2.07 | (0.25) | .22 | 90.39 |
| 26. | Lip Length | 4.68 | (0.37) | 5.09 | (0.43) | -.41 | 108.76 |
| 27. | Ear Protrusion | 2.13 | (0.38) | 1.90 | (0.32) | .23 | 89.20 |
| 28. | Subnasale-Nasal Rt Lth | 5.07 | (0.36) | 5.00 | (0.36) | .07 | 98.62 |
| 29. | Philtrum | 1.40 | (0.25) | 1.50 | (0.24) | -.10 | 107.14 |
| 30. | Lip to Lip Length | 1.80 | (0.29) | 2.53 | (0.36) | -.73 | 140.56 |
| 31. | Menton-Subnasale Lth | 6.99 | (0.53) | 7.52 | (0.61) | -.53 | 107.58 |
| 32. | Face Length | 11.91 | (0.64) | 12.24 | (0.69) | -.33 | 102.77 |
| 33. | Glabella-Vertex | 9.32 | (0.76) | 9.21 | (0.81) | .11 | 98.82 |
| 34. | Nasal Rt-Vertex | 10.95 | (0.72) | 11.02 | (0.78) | -.07 | 100.64 |
| 35. | X-Canthus-Vertex | 11.64 | (0.63) | 11.64 | (0.67) | .00 | 100.00 |
| 36. | Pronasale-Vertex | 14.91 | (0.83) | 14.78 | (0.88) | .13 | 99.13 |
| 37. | Subnasale-Vertex | --- | --- | --- | --- | -- | --- |
| 38. | Stomion-Vertex | 18.24 | (0.79) | 18.49 | (0.90) | -.25 | 101.37 |
| 39. | Menton-Vertex | 22.73 | (0.90) | 23.15 | (0.99) | -.42 | 101.85 |
| 40. | Tragion-Vertex | 13.22 | (0.57) | 13.03 | (0.60) | .19 | 98.56 |
| 41. | Glabella to Wall | 19.76 | (0.72) | 20.01 | (0.68) | -.25 | 101.27 |
| 42. | Nasal Rt to Wall | 19.53 | (0.72) | 19.68 | (0.67) | -.15 | 100.77 |
| 43. | X-Canthus to Wall | 17.01 | (0.70) | 17.38 | (0.68) | -.37 | 102.18 |
| 44. | Pronasale to Wall | 21.81 | (0.81) | 22.02 | (0.74) | -.21 | 100.96 |
| 45. | Subnasale to Wall | --- | --- | --- | --- | -- | --- |
| 46. | Lip Prom to Wall | --- | --- | --- | --- | -- | --- |
| 47. | Chin Prom to Wall | --- | --- | --- | --- | -- | --- |
| 48. | Tragion to Wall | 9.55 | (0.61) | 9.73 | (0.62) | -.18 | 101.88 |

* In Centimeters.
Based on 1965
USAF Survey data.

with the ratio being approximately 100. Of the forty-eight comparisons, the difference is greater than 10% for only three measurements, and greater than 5% for some eleven measurements. These measurements are indicated in Table 5 by the shading. The most marked differences are seen in Variable (11) Nasal Root Breadth, (24) Nose Breadth, and (30) Lip to Lip Length. Because of the marked differences in these means, we should look at the distribution of values with some care. These data are plotted as frequency distributions in Figures 5, 6, and 7. If we were to design for the 95% White range ($\sim\bar{x} \pm 2$ SD), we would in the case of Variable 11 accommodate the lower ~74% of the Black range, for Variable 24 the lower 25%, and for Variable 30 the lower 20% of the Black range. The remaining variables that exceed the 5% level of difference have been plotted as frequency distributions and show a similar pattern of differences in the distribution of values between the Black and White sub-sample. These latter plots are not illustrated here.

Using the Air Force Women's 1968 anthropometric survey data, we can make a similar White-Black comparison for women. The samples here are not matched on age as in the previous comparison, but consist of all the female White (n=1216) and Black (n=131) enlisted women measured in the survey. The results of this analysis are shown in Table 6 (page 24). We see that while data are available for fewer comparisons, the differences that do exist ($\Delta$ >5% variables shaded) show a pattern similar to that found in the male data with the larger discrepancies relating to the

Figure 5

NASAL ROOT BREADTH-MALE*

(Frequency Distributions)

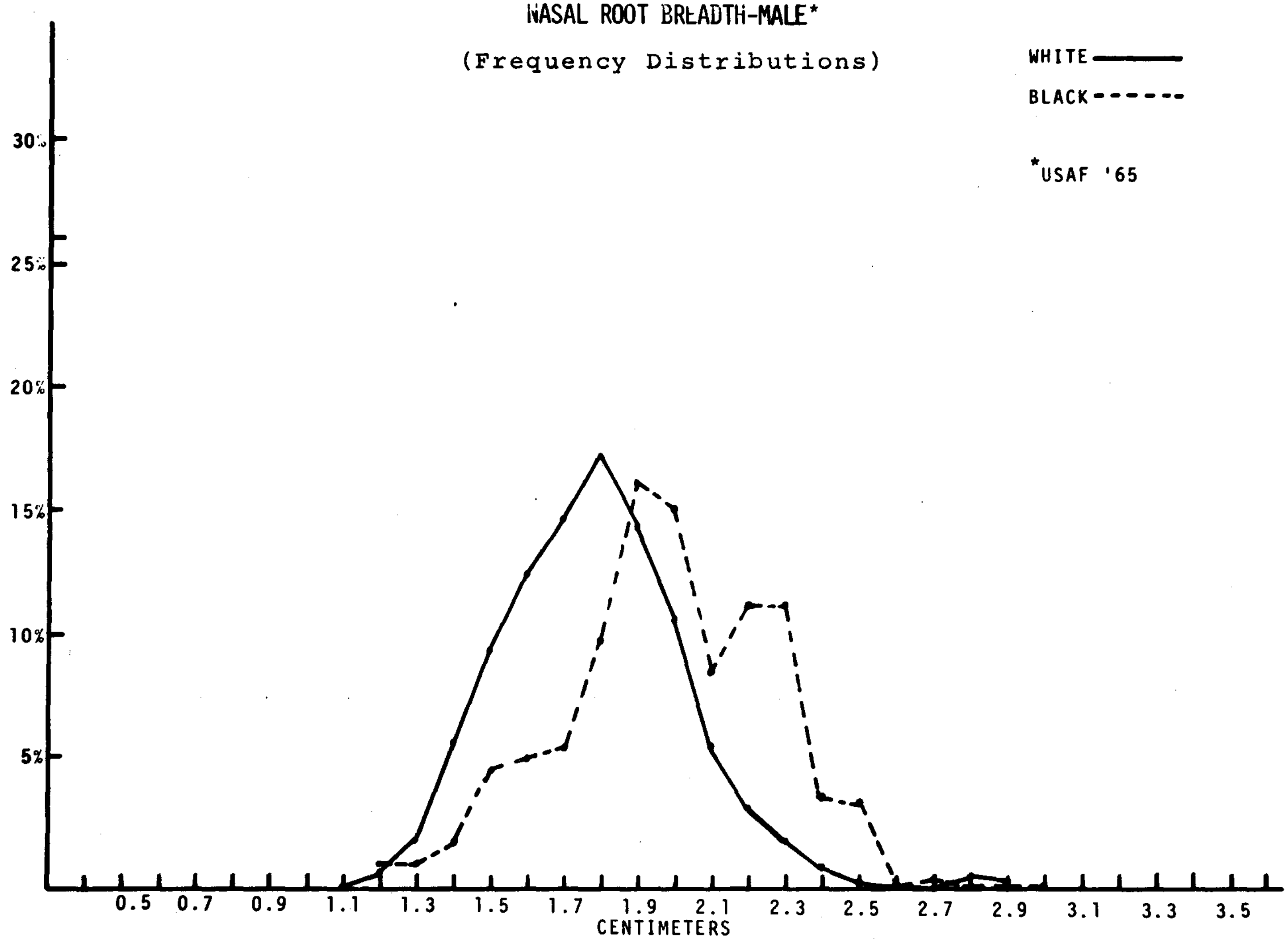


Figure 6

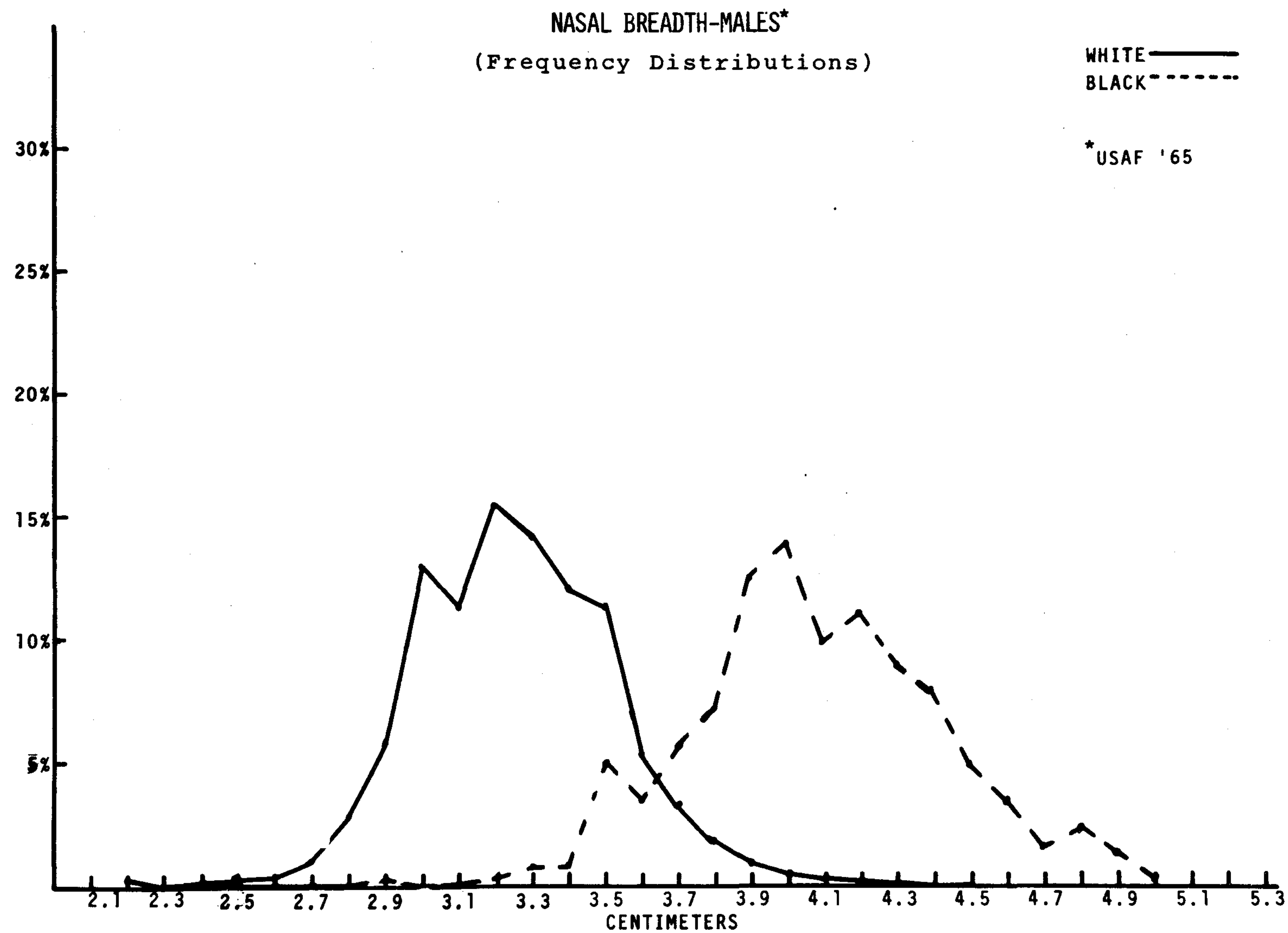

NASAL BREADTH-MALES*
(Frequency Distributions)
WHITE
BLACK
*USAF '65
30%
25%
20%
15%
10%
5%
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
5.1
5.3
CENTIMETERS

Figure 7

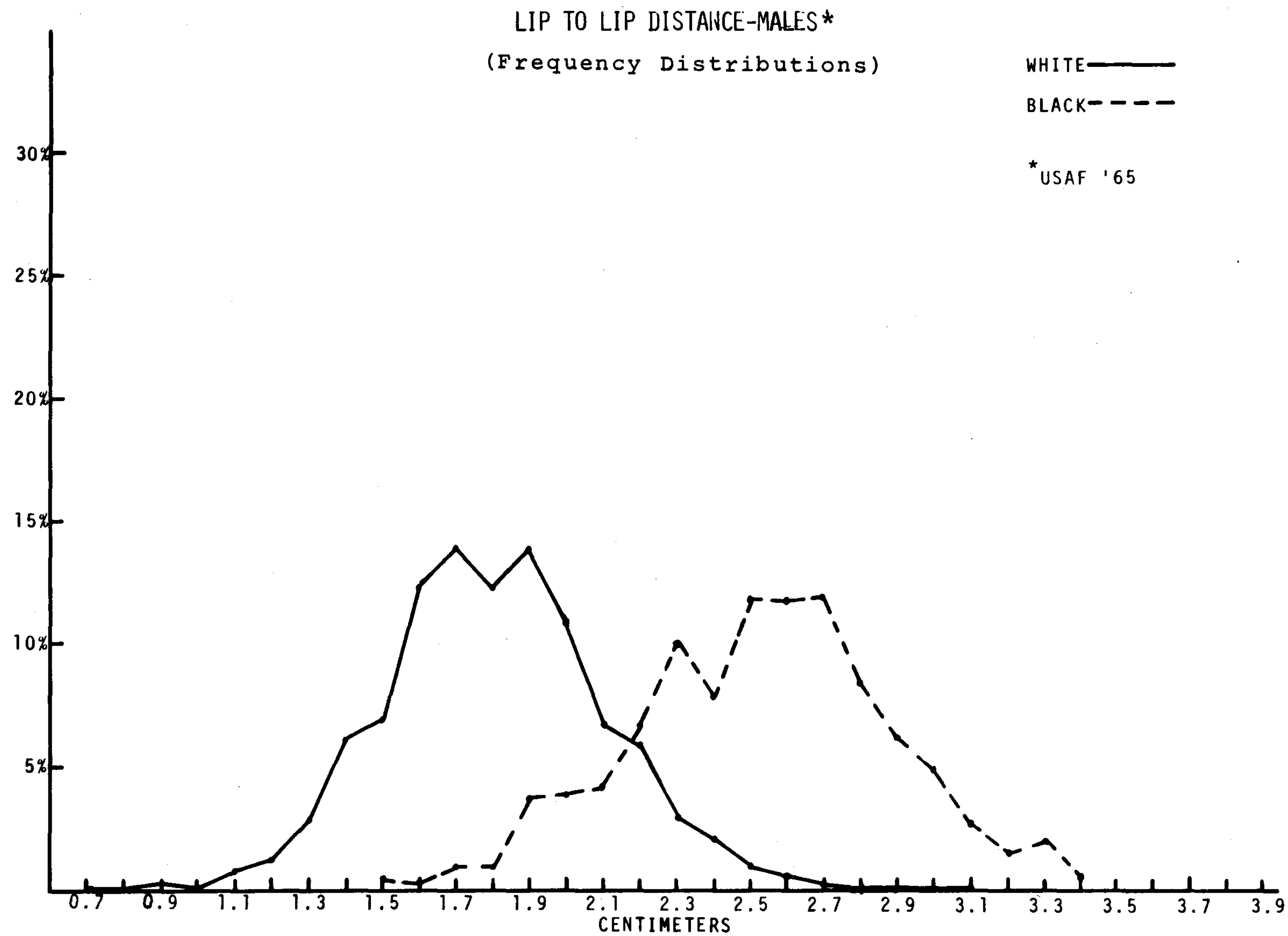

LIP TO LIP DISTANCE-MALES*
(Frequency Distributions)
WHITE
BLACK
*USAF '65
30%
25%
20%
15%
10%
5%
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
CENTIMETERS

Table 6

Comparison of Head and Face Measurements - Mean (SD)*
White and Black (Female)

| | White n=1216 | Black n=131 | Δ W-B | % B/W |
|---|---|---|---|---|
| 1. Head Circ | 54.61 (1.56) | 55.83 (1.53) | -1.10 | 102.01 |
| 2. Sagittal Arc | 34.61 (1.43) | 34.91 (1.21) | -.27 | 100.49 |
| 3. Min Frontal Arc | --- | --- | --- | --- |
| 4. Bit-Coronal Arc | 33.74 (1.36) | 34.67 (1.32) | -.16 | 102.48 |
| 5. Bit-Min Front Arc | --- | --- | --- | --- |
| 6. Bit-Subnasal Arc | --- | --- | --- | --- |
| 7. Bit-Menton Arc | --- | --- | --- | --- |
| 8. Bit-Submandibular | --- | --- | --- | --- |
| 9. Bit-Posterior Arc | --- | --- | --- | --- |
| 10. Head Length | 18.31 (0.67) | 18.66 (0.70) | -.31 | 101.69 |
| 11. Nasal Root Breadth | --- | --- | --- | --- |
| 12. Ear Breadth | 2.96 (0.33) | 3.08 (0.32) | -.12 | 104.05 |
| 13. Ear Length | 5.19 (0.43) | 5.25 (0.45) | -.06 | 101.16 |
| 14. Ear Lth above Tragion | --- | --- | --- | --- |
| 15. Head Breadth | 14.46 (0.58) | 14.37 (0.60) | .08 | 99.45 |
| 16. Max Frontal Br | --- | --- | --- | --- |
| 17. Bitragion Br | 12.82 (0.48) | 12.84 (0.45) | -.02 | 100.16 |
| 18. Bizygomatic Br | 12.87 (0.58) | 12.96 (0.48) | -.09 | 100.70 |
| 19. Bigonial Br | 10.13 (0.53) | 10.22 (0.64) | -.08 | 100.79 |
| 20. Ear to Ear Br | 15.78 (0.96) | 15.56 (0.92) | .20 | 98.73 |
| 21. Biocular Br | 9.60 (0.48) | 10.05 (0.44) | -.40 | 104.15 |
| 22. Interpupillary Br | --- | --- | --- | --- |
| 23. Interocular Br | --- | --- | --- | --- |
| 24. Nose Breadth | 3.13 (0.28) | 3.77 (0.32) | -.58 | 118.18 |
| 25. Nose Protrusion | --- | --- | --- | --- |
| 26. Lip Length | 4.31 (0.40) | 4.85 (0.38) | -.49 | 111.24 |
| 27. Ear Protrusion | --- | --- | --- | --- |
| 28. Subnasale-Nasal Rt L | 4.50 (0.39) | 4.43 (0.39) | .06 | 98.66 |
| 29. Philtrum | --- | --- | --- | --- |
| 30. Lip to Lip Length | --- | --- | --- | --- |
| 31. Menton-Subnasale L | 5.49 (0.49) | 5.85 (0.52) | -.32 | 105.79 |
| 32. Menton-Nasal Rt L | 10.55 (0.59) | 10.70 (0.61) | -.14 | 101.33 |
| 33. Glabella-Vertex | --- | --- | --- | --- |
| 34. Nasal Rt-Vertex | --- | --- | --- | --- |
| 35. X-Canthus-Vertex | 11.66 (0.88) | 12.25 (1.04) | -.53 | 104.52 |
| 36. Pronasale-Vertex | 14.61 (1.12) | 15.15 (1.23) | -.49 | 103.24 |
| 37. Subnasale-Vertex | 15.78 (1.05) | 16.32 (1.20) | -.48 | 103.03 |
| 38. Stomion-Vertex | 17.69 (1.07) | 18.44 (1.23) | -.68 | 103.83 |
| 39. Menton-Vertex | 21.76 (1.09) | 22.56 (1.12) | -.72 | 103.30 |
| 40. Tragion-Vertex | 12.65 (0.75) | 12.91 (0.77) | -.23 | 101.81 |
| 41. Glabella to Wall | --- | --- | --- | --- |
| 42. Nasal Rt to Wall | --- | --- | --- | --- |
| 43. X-Canthus to Wall | 16.23 (0.94) | 17.05 (1.03) | -.82 | 104.54 |
| 44. Pronasale to Wall | 21.06 (0.92) | 21.76 (0.96) | -.63 | 102.98 |
| 45. Subnasale to Wall | 19.54 (0.98) | 20.50 (0.98) | -.86 | 104.38 |
| 46. Lip Prom to Wall | 19.16 (0.98) | 20.50 (1.09) | -1.21 | 106.27 |
| 47. Menton to Wall | 18.10 (1.08) | 18.97 (1.17) | -.78 | 104.29 |
| 48. Tragion to Wall | 10.10 (0.87) | 10.68 (1.00) | -.53 | 105.22 |
| 49. Age | 20.31 (3.60) | 20.85 (3.93) | -.48 | 102.36 |
| 50. Height | 161.92 (5.89) | 161.30 (5.79) | .56 | 99.65 |
| 51. Weight | 125.81(15.40) | 124.14(15.74) | 1.51 | 98.80 |

* In Centimeters.
Age in years, weight in pounds.
Based on 1968 WAF Survey.

dimensions of the nose and lower face. From this analysis we must conclude the design values based upon the White sample, for some facial dimensions, would not accommodate the total range of variability that exist in the Black sample.

It should be noted, however, that the majority of design values based upon either group would largely accommodate members of the other group. In those instances where the differences between the groups are large, a designer must be aware of and adjust the design values to accommodate the wider range of variability.

The number of racial/ethnic groups that make up the U. S. population is truly large and it is not possible to isolate them all for analysis from existing data. In many of the military surveys, ethnic origins were not ascertained from the subjects and no reasonable method exists for obtaining this from the available background information. Data on ethnic origins were, however, obtained in the 1966 anthropometric surveys of the Army (V), Navy (VIII) and Marines (IX), (Table 2). These surveys contain far fewer variables of the head and face than are desired for our purpose and the comparisons are limited in comprehensiveness. The subjects in these surveys were asked to indicate their ethnic derivation or national extraction. In the larger Army series, for example, about 45% of the total sample listed themselves as American White (29.4%), American Black (14.6%), and American Indian (1.5%) without further designation. An additional

33% of the sample listed themselves as of German, Irish, English or Italian extraction with the remaining 22% designating some 33 other ethnic backgrounds.

The limited head and face anthropometry from these three surveys are, therefore, compared for the larger racial and ethnic subdivisions.

A comparison of head and facial measurements for a series of ethnic groups is given in Table 7. These data are from the 1966 U. S. Army anthropometric survey and the groups included in the table represent all designations having a minimum of twenty respondents. The table lists the seventeen subgroups isolated for analysis having a minimum of twenty subjects in each, the sample size of each group and the deviation in percent for each subgroup mean value from the total sample mean for seven measurements of the head and face.

A more rigorous comparison would be made by testing each subgroup value against every other such value; however, as our primary concern is with the variation from the total group, this method of comparison is a simple and practical technique for detecting subgroup differences. A review of the differences shown in Table 7 indicate that by and large the subgroups deviate only in a minor amount from the total group mean with some 82% of the differences being within $\pm$ one percent of the group mean. In only five cases are the deviations greater than two percent and these are American Black Interpupillary Breadth

Table 7

RACIAL/ETHNIC COMPARISON

of

SELECTED HEAD AND FACE MEASUREMENTS*

| Racial/Ethnic Group | N | Face Lgth | Face Br | Inter-Pupillary Breadth | Head Lgth | Head Br | Head Circ | Tragion-Vertex Ht |
|---|---|---|---|---|---|---|---|---|
| Total Sample | 6682 | 120.3 | 139.9 | 61.3 | 194.7 | 152.7 | 561.1 | 132.3 |
| American White | 1960 | 99.6% | 99.6% | 99.5% | 100.2% | 99.7% | 100.0% | 99.9% |
| American Black | 982 | 101.5 | 100.1 | 104.9 | 101.3 | 91.1 | 100.5 | 99.8 |
| American Indian | 120 | 99.7 | 100.6 | 99.2 | 100.3 | 99.6 | 99.8 | 100.0 |
| Mexican | 113 | 101.3 | 101.6 | 99.5 | 98.8 | 99.2 | 99.9 | 100.1 |
| Puerto Rican | 125 | 98.6 | 100.2 | 100.8 | 97.1 | 99.2 | 98.7 | 99.8 |
| Spanish | 74 | 100.1 | 99.9 | 98.5 | 97.8 | 99.5 | 98.7 | 100.2 |
| Japanese | 26 | 101.1 | 105.4 | 100.8 | 98.5 | 103.4 | 100.3 | 100.3 |
| English | 558 | 99.6 | 99.9 | 98.5 | 100.2 | 100.1 | 100.1 | 100.2 |
| Irish | 864 | 99.9 | 100.1 | 98.9 | 100.1 | 100.3 | 100.2 | 100.1 |
| Scots | 169 | 99.7 | 100.3 | 99.3 | 100.6 | 100.4 | 100.5 | 100.2 |
| Welsh | 21 | 99.2 | 100.5 | 99.2 | 99.0 | 101.2 | 99.6 | 100.3 |
| French | 273 | 99.2 | 99.3 | 98.7 | 99.1 | 99.5 | 99.4 | 100.1 |
| German | 1080 | 100.1 | 100.2 | 98.4 | 99.7 | 99.4 | 100.0 | 100.1 |
| Polish | 218 | 99.7 | 100.9 | 99.0 | 98.0 | 100.9 | 99.7 | 100.0 |
| Swedish | 134 | 100.1 | 100.3 | 99.2 | 100.3 | 100.6 | 99.6 | 100.0 |
| Dutch | 147 | 99.3 | 100.1 | 98.9 | 100.1 | 100.3 | 100.0 | 100.1 |
| Italian | 319 | 99.8 | 99.9 | 99.2 | 99.2 | 99.9 | 99.6 | 100.0 |

* U. S. Army 1966 data measurement values in mm and comparative values a ratio of subgroup mean values to total sample mean values.

(4.9%), Puerto Rican and Spanish Head Length (-2.9 and -2.2%), and Japanese Face Breadth and Head Breadth (+5.4 and +3.4%). These differences are of sufficient magnitude to warrant further analysis of these subgroups. The U. S. Navy and U. S. Marine samples were analyzed in a similar fashion giving essentially identical results and are, therefore, not reproduced here.

The most comprehensive data for further analysis in terms of the number of head and face variables measured are from the U. S. Air Force and U. S. Naval Aviator studies (Table 2, Columns I, II, III and VII). It is unfortunate that in none of these surveys was ethnic derivation recorded although the primary racial affinity (Caucasian, Negro, Oriental) were noted. In examining these survey samples, it was found that the most appropriate data for further analysis was from the 1965 U. S. Air Force Survey. The White and Black subgroups used in this comparison are those previously described above and enumerated in Table 5. An Oriental subgroup was obtained which, while considerably smaller than was desired (n=7), is the largest obtainable from the more comprehensive data sources.

In seeking to isolate a Spanish ethnic subgroup, all subjects in the Caucasian racial group with a Spanish form of surname were sorted into a single group. This group was then subdivided into categories on the basis of their birthplace and the birthplace of their parents. The subjects born in Spain or whose parents were born in Spain were few in number (n=5) and it was decided to combine them with the Mexican subgroup. This latter subgroup consisted of all subjects who were born in Mexico or had indicated that one or both of his parents had been born in Mexico. A total of 69 individuals was classified as belonging to this subgroup which, while titled "Spanish-American," undoubtedly exhibits a strong American Indian genetic admixture. It was possible in this classification process to identify and isolate a Puerto Rican subgroup of small size (n=16) as well and this was also included in our analysis.

This method of obtaining the various subgroups for comparative study is admittedly less than perfect but after a number of alternate methods proved futile, was found to be the only reasonable approach possible. It is rather ironic that in recent years in the United States the strong emphasis on ethnic subgroup identity has resulted in the avoidance in many studies of questions relating to racial or ethnic affiliations. Attempts to isolate additional subgroups, for example, American Indian, proved to be totally unsuccessful.

The results of this comparison are shown in Table 8. The data enumerated here are the actual differences in mean values $\Delta$ (White sample mean minus subgroup sample mean), as well as the ratio of the subgroup to the White mean. Differences which exceed 5% are highlighted in this table. It is of interest to note that the differences seen are similar for the various subgroups; that is, they relate to the same facial area and differ from the White group in the same way. The contrasted subgroups have, in general, broader faces and noses with less nose protrusion and wider mouths.

Table 8

Comparison of Head and Face Measurements - Δ and % - Ethnic Subgroups Drawn from 1965 Survey*

| | Black | | Span/Amer | | Puerto Rican | | Oriental | |
|---|---|---|---|---|---|---|---|---|
| | ΔW-B | % B/W | ΔW-S | %SA/W | ΔW-PR | %PR/W | ΔW-O | % O/W |
| 1. Head Circ | -.40 | 100.72 | .43 | 99.23 | .75 | 98.66 | .11 | 99.80 |
| 2. Sagittal Arc | .04 | 99.89 | .32 | 99.15 | 1.06 | 97.18 | -.54 | 101.44 |
| 3. Min-Frontal Arc | -.09 | 100.76 | .16 | 98.64 | .14 | 98.81 | -.16 | 101.36 |
| 4. Bit-Coronal Arc | .16 | 99.54 | -.23 | 100.66 | .02 | 99.94 | -.76 | 102.19 |
| 5. Bit-Min Front Arc | -.17 | 100.56 | .08 | 99.74 | .10 | 99.67 | -.42 | 101.39 |
| 6. Bit-Subnasale Arc | -.79 | 102.79 | -.57 | 102.01 | .09 | 99.68 | -.97 | 103.43 |
| 7. Bit-Menton Arc | -.68 | 102.20 | -.39 | 101.26 | .30 | 99.03 | -.60 | 101.94 |
| 8. Bit-Submandibular Arc | -.16 | 100.56 | -.40 | 101.40 | .40 | 98.60 | -.47 | 101.64 |
| 9. Bit-Posterior Arc | .09 | 99.64 | .04 | 99.84 | .45 | 98.19 | -.34 | 101.36 |
| 10. Head Length | -.25 | 101.28 | .40 | 97.95 | .50 | 97.44 | .36 | 98.16 |
| 11. Head Max Dia (Ment) | -.41 | 101.64 | -.06 | 100.24 | .25 | 99.00 | -.39 | 101.56 |
| 12. Head Max Dia (Nuch) | -.04 | 100.21 | .06 | 99.69 | .27 | 98.59 | -.08 | 100.42 |
| 13. Ear Length | .28 | 95.52 | -.16 | 102.56 | .25 | 96.00 | -.19 | 103.04 |
| 14. Ear Length above Tragion | .11 | 96.08 | -.12 | 104.27 | .10 | 96.44 | .05 | 98.22 |
| 15. Ear Breadth | .02 | 99.42 | -.11 | 103.18 | .18 | 94.80 | .02 | 99.42 |
| 16. Ear Protrusion | .23 | 89.20 | -.03 | 101.41 | .01 | 99.53 | -.14 | 106.57 |
| 17. Head Breadth | .06 | 99.60 | -.14 | 100.92 | -.14 | 100.92 | -.55 | 103.63 |
| 18. Biauricular Breadth | .87 | 95.27 | -.12 | 100.65 | -.06 | 100.33 | -.85 | 104.62 |
| 19. Bitragion Breadth | .07 | 99.49 | -.20 | 101.47 | -.04 | 100.29 | -.58 | 104.26 |
| 20. Bizygomatic Breadth | -.02 | 100.14 | -.23 | 101.66 | -.15 | 101.08 | -.63 | 104.55 |
| 21. Max Frontal Dia | -.11 | 100.96 | -.10 | 100.88 | .03 | 99.74 | -.13 | 101.39 |
| 22. Bigonial Dia | .11 | 98.96 | -.20 | 101.89 | .08 | 99.25 | -.46 | 104.34 |
| 23. Biocular Dia | -.52 | 105.67 | -.17 | 101.85 | -.17 | 101.85 | -.46 | 105.02 |
| 24. Interpupillary Dia | -.36 | 105.91 | .02 | 99.67 | -.08 | 101.31 | -.37 | 106.08 |
| 25. Interocular Dia | -.22 | 107.05 | -.05 | 101.60 | -.01 | 100.32 | -.28 | 108.97 |
| 26. Nasal Root Breadth | -.21 | 111.80 | -.04 | 102.25 | .04 | 97.75 | -.13 | 107.30 |
| 27. Nasal Breadth | -.82 | 125.31 | -.24 | 107.41 | -.14 | 104.32 | -.35 | 110.80 |
| 28. Nose Protrusion | .22 | 90.39 | .11 | 95.20 | .14 | 93.89 | .20 | 91.27 |
| 29. Philtrum Length | -.10 | 107.14 | -.03 | 102.14 | -.07 | 105.00 | -.06 | 104.29 |
| 30. Lip-to-Lip Dist | -.73 | 140.56 | -.16 | 108.89 | -.19 | 110.55 | -.21 | 111.67 |
| 31. Lip Length | -.41 | 108.76 | -.12 | 102.56 | .06 | 98.72 | -.29 | 106.20 |
| 32. Lip Length Smiling | -.38 | 106.93 | -.23 | 104.20 | -.10 | 101.82 | -.49 | 108.94 |
| 33. Menton-Subnasale Lgth | -.53 | 107.58 | -.05 | 100.72 | -.17 | 102.43 | -.14 | 102.00 |
| 34. Menton-Nasal Root Dep | -.33 | 102.77 | -.11 | 100.92 | -.11 | 100.92 | .04 | 99.66 |
| 35. Subnasale-Nasal Root Dep | .07 | 98.62 | -.13 | 102.56 | .02 | 99.61 | .16 | 96.84 |
| 36. Vertex-Glabella Height | .11 | 98.82 | .15 | 98.39 | .31 | 96.67 | -.34 | 103.65 |
| 37. Vertex-NRD Height | -.07 | 100.64 | .19 | 98.26 | .17 | 98.45 | -.52 | 104.75 |
| 38. Vertex-Ext Canthus Hgt | --- | 100.00 | .11 | 99.05 | .19 | 98.37 | -.36 | 103.09 |
| 39. Vertex-Pronasale Height | .13 | 99.13 | -.01 | 100.07 | .19 | 98.73 | -.28 | 101.88 |
| 40. Vertex-Stomion Height | -.25 | 101.37 | -.07 | 100.38 | .18 | 99.01 | -.49 | 102.69 |
| 41. Vertex-Menton Height | -.42 | 101.85 | -.02 | 100.09 | .15 | 99.34 | -.44 | 101.94 |
| 42. Vertex-Tragion | .19 | 98.56 | .08 | 99.39 | .09 | 99.32 | -.47 | 103.56 |
| 43. Wall-Glabella Dist | -.25 | 101.27 | .34 | 98.28 | .47 | 97.62 | .37 | 98.13 |
| 44. Wall-NRD Dist | -.15 | 100.77 | .29 | 98.52 | .44 | 97.75 | .42 | 97.85 |
| 45. Wall-Ext Canthus Dist | -.37 | 102.18 | .16 | 99.06 | .42 | 97.53 | -.15 | 100.88 |
| 46. Wall-Pronasale Dist | -.21 | 100.96 | .16 | 99.27 | .42 | 98.07 | .55 | 97.48 |
| 47. Wall-Stomion Dist | -.96 | 104.72 | -.07 | 100.34 | .16 | 99.21 | .09 | 99.56 |
| 48. Wall-Menton Dist | -.17 | 100.92 | .04 | 99.78 | .23 | 98.75 | .51 | 97.23 |
| 49. Wall-Tragion Dist | -.18 | 101.88 | .28 | 97.07 | .39 | 95.92 | .52 | 94.55 |

* U. S. Air Force 1965 data measurement values in centimeters and comparative values a ratio of subgroup mean values to total sample mean values.

Additional subgroup evaluations would be desirable but are not possible using the available data.

The various sources of intra and inter-individual variability have been examined and a series of conclusions can be derived with regard to respirator facepiece sizing and design. In general, we may conclude:

1) Major intra-individual head and face change occurs prior to a worker entering the labor force. Intra-individual changes associated with aging are probably not significant for respirator sizing and design purposes. Intra-individual sources of variation can be largely ignored in facepiece design.

2) Sexual differences are of significant magnitude to warrant consideration. While a broad area of overlay in size based upon key dimensions does exist, the female face is sufficiently smaller than the male face to warrant consideration in facepiece sizing and design. While unable to prove our assumption that the male face of a given size based upon some selective dimension equates with a female face of that size and the reverse, we are inclined to continue the use of this assumption as being not unreasonable.

3) Inter-individual variability between racial and ethnic groups has been documented which is of sufficient magnitude to warrant consideration in facepiece design. In our analysis, we have tested the subgroup data generally against White subgroup data which would cause the differences to appear larger than if

the total population data were to be used. Irrespective of this, the differences which have been noted are real and significant in facepiece design.

4) Additional subgroup analysis is desirable, especially for the Oriental subgroups for whom the sample size was extremely small.

## Section II

## DESIGN AND SIZING CONCEPTS

Where a body of anthropometric data that is available is believed adequate to describe a population, the next question becomes one of determining how to use these data in a particular design problem.

A widely held concept in design revolves about designing for the 'average' or 'average man.' As previously pointed out, the arithmetic mean or average can be computed for any dimension measured and if the sampling is adequate, is an estimate of central tendency for that variable for the population. When the average is used in conjunction with some measure of variability, such as the standard deviation, it becomes a useful descriptive tool to specify population parameters. Because it is a form of minimum error - it lies closer to all other values in a distribution of values than any other particular statistic - then it appears logical to assume that it must serve some important role in design.

The use of the average despite its apparent value as a design datum can often lead to grave consequences. If, for example, the average value of nose protrusion is used as the design criteria for clearance of the facepiece in the nose region, it would soon be apparent that only half the potential users could be accommodated. Those individuals having a nose protrusion greater than average would not have sufficient nose clearance in the facepiece and could not be properly fitted.

In addition to this, it is often assumed that an average human face will be average in all facial dimensions. This is a rather common extension of the idea that the body proportions are somewhat constant and that a small face is a miniature version of the average face and the large face an expanded version of it.

In a study of the concept of the average man, Daniels (1952) tested the assumption of what measurement values constitute the average man using ten dimensions useful in clothing design. As Daniels' example is not particularly pertinent here, we have taken the liberty of duplicating his work using 10 dimensions of the face. The criteria of average is defined in a broad sense in this exercise in that any individuals whose measurement for a particular dimension fell within $\pm$ 0.5 SD of the arithmetic mean was considered to be average for that dimension.* The number of subjects having a value for the 10 selected dimensions of the face using the 1967 USAF sample is shown in the following table. The table illustrates at each step the number of individuals who are considered average for that dimension, as well as for all preceding dimensions listed above it. For example, at step two, 363 subjects are of average face breadth from the sample of 909 subjects who were of average face length.

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* The mean plus or minus one-half standard deviation includes, in a normally distributed variable, the ∿ central 38 percent of the measurements with its limits.

Table 9

The Average Face*

| | Variable | Range | Number Included | Percent of Sample |
|---|---|---|---|---|
| 1. | Face Length | 117-123 (mm) | 909 | 37.6 |
| 2. | Face Breadth | 140-145 | 363 | 15.0 |
| 3. | Lip Length | 50- 54 | 154 | 6.4 |
| 4. | Subnasale-Nasal Root Lgth | 49- 53 | 84 | 3.5 |
| 5. | Nose Breadth | 34- 39 | 42 | 1.7 |
| 6. | Pronasale to Wall | 223-231 | 14 | .6 |
| 7. | Maximum Frontal Br | 114-118 | 6 | .2 |
| 8. | Interocular Br | 32- 35 | 2 | .08 |
| 9. | Interpupillary Br | 61- 65 | 1 | .04 |
| 10. | Bitragion-Subnasale Arc | 288-298 | 0 | 0 |

* U. S. Air Force 1967 data

It will be noted from the table that approximately 38 percent of the sample is initially included as having an average face length as defined. With each succeeding step, the number of individuals still classified as average is rapidly reduced until in the the tenth and final step none of the original 909 individuals remains. We could change the dimensions used in this analysis or vary their order and obtain slightly different results but could not manipulate it sufficiently to warrant changing the conclusion that the average man is a statistical concept only and does not exist in nature.

From the above, it must be clear that the average is a poor design criteria and its use can be most inappropriate in attempting to accommodate a population in a design solution.

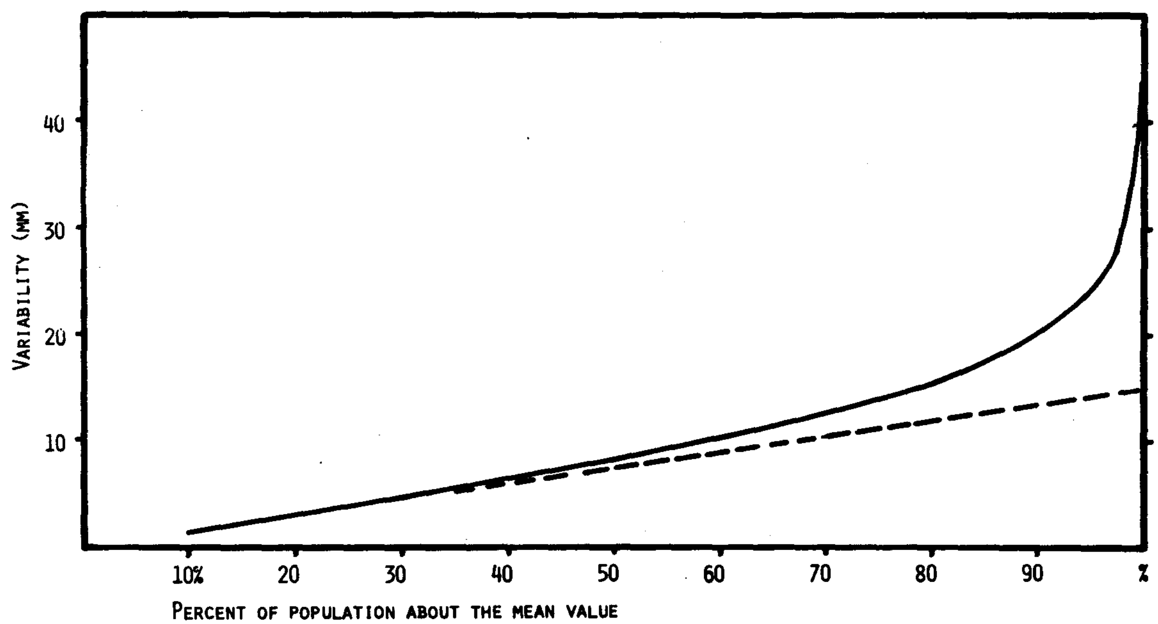
The more sophisticated designer is apt to think in terms of some other design concept which incorporates the tail of the distribution of values rather than the average. Ideally, a designer should cover the entire range of variation in a population but in practice this can seldom be achieved successfully. A small percentage of individuals on either end of the normal curve often requires so many additional sizes and/or range of adjustability in the end item, that their inclusion is impractical or uneconomical. In a general term, it is almost impossible to design for more than 90 - 95 percent of the population without compromising the effectiveness of an item of personal protective equipment.

One might, for example, examine the range of variability for a single dimension to demonstrate the range of variability associated with various percentages of the population. Using the dimension of face length to examine the center half of the USAF 1967 sample, that is those individuals that fall between the 25th and 75th percentiles, we find the range of variability to be 8 mm (116 - 124 mm). The range of variability for the central 90 percent of the series is 20 mm and the central 98 percent 28 mm, with the total variability from smallest face length to largest in this series being 46 mm.

These data are plotted as a line graph in Figure 8. The X axis here denotes the percentage of the population about the mean value; for example, 10 percent signifies the individuals who fall in the distribution between the 45th and 55th percentiles, the 20 percent the individuals between the 40th and 60th percentiles,

Figure 8

FACE LENGTH VARIABILITY BY PERCENTILE GROUPS



etc. The Y axis denotes the variability in mm of measured face length for the specified groups. It is apparent from this line graph that the increase in variance is relatively constant in the middle of the distribution but increases very rapidly toward the tails of the distribution. The dotted line on the graph represents the variance that would be anticipated based upon the central third of the distribution values. This line graph is quite characteristic of the variance that can be expected in human body measurements.

As a consequence, it is a general practice to study for a design solution only that part of the population which constitutes the central 90 to 95 percent of the total, based upon some selective criteria such as face length in the above example. The extreme values in the distribution are thus disregarded in the analysis. In reality, it is often found that when a design is successful for the design population, it will also accommodate a portion of the individuals who lie beyond the design limits but seldom, if ever, will such a solution accommodate all potential users without some custom fabrication or modification.

The concept of the design limits is thus widely held and in some ways can be extremely useful, but has taken on some unfortunate interpretations. We find, for example, that the 5th and 95th percentile values from the design population have become accepted as the only proper design values to be used to accommodate the population. These values have then been formulated as the

5th and 95th percentile body form, head form, etc., and designers have worked to accommodate these forms with the rationale that by so doing they would also accommodate in their design all the combinations of size and shape that fall between these limits.

The reservations expressed about the 'average man' should be intensified in many respects in dealing with the 5th and 95th percentile forms. Not only are the percentile forms unrealized in nature, they are also statistically impossible. If, for example, the 95th percentile value for lower face length and also for upper face length are used in a face form, then the sum of these values exceeds the 95th percentile value of total face length by $\sim$5 mm (USAF 1967 data). Similarly, the sum of the two 5th percentile values is $\sim$6 mm less than the 5th percentile value of face length. This is true of the other dimensions as well and relates to the less than perfect correlation of the various dimensions of the body with one another. Only if all the dimensions of the body were perfectly correlated would the sum of part-values equate with the total. The exception to this statement is with the 50th percentile values. In a normal distribution these values will approximate the average value and would be expected to integrate together in a similar fashion.

The most common solution to the problem of inconsistencies of values has been to select as many parameters as possible and set these to the extreme (5th/95th) percentile value and then let the values for the remaining variables fall as they must to arrive at a complete form. What happens, of course, is that we find the finished percentile form exhibiting extremely long legs and short torso or the reverse depending upon what the designer believed was important in that particular form. These then become established as the 5th or 95th or some other percentile 'standard' and are widely used for many applications whether or not they are particularly appropriate for a specific design solution.

If we are critical of the existing design concepts, what can be offered as being more valid and usable? The design concept that is necessary is one that is specifically related to the end item to be designed and the range of the population that must be accommodated. It may be required, for example, to design a single work station to accommodate the body size, arm reach, etc. of adult male and female workers, or a size range of full body protective garments for adult males who work in hazardous environments. Whatever the requirements, an effective design solution can be developed with the same general approach.

The major steps involved in the proper anthropometric design analysis include:

1. Select the appropriate body of data for analysis.
2. Selection of the one or more key or basic sizing dimensions.
3. Selection of the range of the key dimension with the purpose of establishing a sizing category of end item that will adequately accommodate all those individuals who fall within the category.

4. Develop for each sizing category all other dimensional data which would be of use in the design or sizing of the item.

5. Conversion of the summary data to the proper design value for the end item in terms of fit and function.

6. Establish estimates of the sizing tariff.

An adequate body of anthropometric data does not exist for every subgroup which a designer may be interested in. However, sufficient data are available for approximating much of the subgroup anthropometry with a fair degree of confidence. The type and quantity of existing anthropometric data has been discussed above and this is gradually being supplemented by additional studies. Currently, two major anthropometric studies of special groups are being carried out in the United States. One study, being conducted by the Highway Safety Research Institute at the University of Michigan, involves gathering design data for infants and children; the other, being conducted by the Naval Electronics Laboratories, San Diego, California, is an anthropometric survey of law enforcement personnel. As more such data become available the easier it becomes for selecting the most appropriate body of information in design studies for specific groups.

The choice of the key or basic sizing dimension in a design analysis is of critical importance, yet the choice is seldom clear cut. The key dimensions should have certain attributes such that:

1. They are dimensions which can be conveniently and accurately measured.
2. They are an integral part of the fabrication of the end item.
3. They have a high degree of relationship with the other dimensions which are important to the design of the item.

The selection of the key dimensions from a series of variables, all of which may have the attributes cited above, will often resolve itself on the basis of which of the variables exercises the maximum control over the other measures of size. Here we are referring to the degree of relationship among variables which is quantified by the statistic of the correlation coefficient. The correlation coefficient (r) can range from -1.00 through to +1.00, with the first figure being a perfect negative relationship, the last a perfect positive relationship and the control value of 0 as might be surmised indicating zero order or no relationship. If the various dimensions of the head and face each correlated 1.00 with face length, then for every given face length we would have a single predictable accurate value for each of the other dimensions. When, on the other hand, the relationship approaches zero, any resulting estimates derived based upon face length will be of little more accuracy than if each individual's values were set equal to the group mean for each dimension. The higher the correlation coefficient of the key variable with the other design parameters, the more efficient is a sizing program. As we control the width of the key dimension in a sizing scheme, through the relationship of the key dimension to the other variables, we in effect tend to control the other sizing variances as well.

The search for key dimensions thus may center about a correlational or relationship analysis of the variables involved in the design problem. One might, for example, find that no single dimension provided the necessary 'control' and would search for a pair of key dimensions. An obvious example of this type of sizing is in men's ready to wear slacks which have a pair of dimensions such as waist circumference and inseam length. In this manner, one would look to each of the key dimensions to 'control' a different aspect of size as, in our example above, where waist circumference relates to weight or volume and inseam length to linearity. Normally there is no need or advantage offered by using more than one or two key dimensions.

After selecting the key or sizing dimensions, a second step would be to select intervals of the key dimensions as the width of the sizing or design categories. A series of considerations may be involved in making this decision. These considerations may be specified as the number of sizes for a particular end item that are logistically feasible, the maximum permissible width of a sizing category in terms of the key dimensions that may be accommodated with a specific material, or the possible range of adjustability permissible within the end item. Any number of pertinent factors may enter into this stage of selecting the number of sizes that will be necessary to accommodate the user population.

If the number of sizes that can be permitted are specified due to problems of logistics or some other consideration, then the problem becomes one of determining how to accommodate the population variance within the specified sizes. This often means that new materials must be used in the end item or perhaps a range of adjustability must be provided in the end item to accommodate the variance of that size category. One might see, for example, a manufacturer develop a new rubber for respirator facepieces that would conform better to the variations in face size to replace his present facepiece material and thereby reduce the overall number of sizes needed to accommodate the population.

At some point, a decision will be made as to the trade-off of the various design considerations and the sizing category intervals will be established. Such a series of hypothetical sizing categories are shown in Figure 9. Here we assume it was established through analysis that face length - face breadth were the proper key dimensions for our purpose. It was established through tests that $\sim$16 mm variance in face length and $\sim$20 mm variance in face breadth could be accommodated in a single respirator facepiece on the basis of the physical properties of the facepiece material. The size intervals were then plotted on a bivariate distribution of population variance for these two variables and a four size full facepiece respirator sizing program outlined. The sizing categories are placed on

Figure 9

Hypothetical Four Size Respirator Facepiece Program

A Bivariate Frequency Table for Face Length and Face Breadth (Combined USAF 1967 and WAF 1968)*

Face Breadth

| Face Length | 108.5 | 110.5 | 112.5 | 114.5 | 116.5 | 118.5 | 120.5 | 122.5 | 124.5 | 126.5 | 128.5 | 130.5 | 132.5 | 134.5 | 136.5 | 138.5 | 140.5 | 142.5 | 144.5 | 146.5 | 148.5 | 150.5 | 152.5 | 154.5 | 156.5 | 158.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 142.5 | | | | | | | | | | | | | | | | | | / 1 | | | | | | / 1 | | | / 2 |
| 140.5 | | | | | | | | | | | | | | | / 1 | | | / 1 | / 2 | | | | | | | | / 4 |
| 138.5 | | | | | | | | | | | | | | | | | | | / 1 | | / 1 | / 1 | | | | | / 3 |
| 136.5 | | | | | | | | | | | / 1 | | | | | / 1 | | / 2 | / 1 | / 3 | / 1 | | / 1 | / 1 | | | / 11 |
| 134.5 | | | | | | | | | | | | / 1 | | | / 1 | / 2 | / 2 | / 3 | / 2 | / 2 | / 4 | / 4 | | | | | / 21 |
| 132.5 | | | | | | | | | | | | | | / 3 | / 4 | / 5 | / 7 | /10 | / 4 | / 6 | / 4 | / 2 | LW | | | | / 45 |
| 130.5 | | | | | | | | | | | | | / 2 | / 3 | / 5 | / 5 | / 9 | /15 | / 9 | /11 | / 4 | / 4 | | / 1 | / 1 | / 1 | / 70 |
| 128.5 | | | | | | | | | | | | / 1 | / 1 | / 4 | / 7 | 1/14 | /17 | /16 | /13 | /15 | /16 | / 4 | /10 | / 5 | / 1 | / 1 | 1/ 125 |
| 126.5 | | | | | | | | 1/ | | | | 1/ | / 2 | / 3 | / 9 | /12 | /22 | /38 | /33 | /27 | /14 | / 8 | / 7 | / 5 | / 2 | | 2/ 182 |
| 124.5 | | | | | | | | | | 1/ | | 1/ 4 | / 2 | /14 | /14 | /20 | 1/39 | /37 | /45 | /35 | /15 | /11 | /11 | / 8 | / 2 | / 1 | 3/ 258 |
| 122.5 | | | | | | | | | | 1/ | / 1 | 1/ 1 | 2/ 7 | 1/11 | /18 | /37 | 2/48 | /54 | /46 | /32 | /26 | /15 | / 7 | / 2 | / 1 | | 7/ 306 |
| 120.5 | | | | | MN | | 2/ | 1/ | 3/ | 1/ | 2/ 1 | 3/ 3 | 1/ 6 | 3/12 | 2/36 | /40 | /43 | /61 | 1/38 | /36 | /35 | /11 | /12 | / 1 | | | 19/ 335 |
| 118.5 | | | 1/ | | | | 1/ | 1/ | 3/ | 3/ | 5/ 1 | 7/ 4 | 3/13 | 7/11 | 7/32 | 1/19 | 1/45 | /47 | /48 | /30 | / 9 | / 4 | / 5 | | | | 40/ 268 |
| 116.5 | | | | 1/ | 3/ | 2/ | 3/ | 4/ | 5/ 1 | 5/ | 5/ 1 | 12/ 2 | 6/10 | 9/15 | 4/27 | 2/32 | 4/35 | 1/34 | /39 | 1/27 | /12 | / 6 | / 1 | / 4 | | | 67/ 246 |
| 114.5 | | 1/ | | | 1/ | | 5/ | 6/ | 9/ 1 | 11/ 2 | 7/ 1 | 13/ 1 | 3/14 | 14/22 | 3/26 | 6/30 | 3/39 | 1/34 | 2/24 | /15 | /13 | / 4 | | / 2 | / 1 | / 1 | 85/ 230 |
| 112.5 | | | | | | | 6/ | 3/ | 15/ | 18/ 1 | 12/ 1 | 26/ 2 | 21/ 4 | 20/11 | 10/12 | 4/14 | 5/20 | 1/23 | 2/22 | / 9 | / 8 | / 5 | / 1 | | / 1 | | 143/ 134 |
| 110.5 | | | | 1/ | 4/ | 3/ | 16/ | 10/ | 14/ | 21/ | 19/ 1 | 29/ 1 | 29/ 2 | 19/13 | 14/11 | 6/13 | 4/16 | 1/18 | / 8 | 1/ 5 | / 9 | / 2 | / 2 | / 2 | | | 191/ 103 |
| 108.5 | | | 1/ | 3/ | 3/ | 4/ | 11/ | 8/ | 24/ | 27/ | 20/ | 36/ | 29/ 2 | 21/ 5 | 13/ 5 | 6/ 4 | 8/ 8 | 2/ 8 | / 8 | / 2 | / 2 | | / 1 | | | | 216/ 45 |
| 106.5 | | 2/ | 2/ | 2/ | 3/ | 1/ | 17/ | 12/ | 23/1 | 27/ | 25/ 1 | 48/ | 20/ | 27/ 1 | 12/ 2 | 10/ 1 | 5/ 5 | / 2 | / 2 | / 1 | / 1 | MW | / 1 | | | | 246/ 18 |
| 104.5 | | 2/ | 1/ | 6/ | 1/ | 2/ | 13/ | 18/ | 31/ | 39/ 1 | 29/ | 55/ | 26/ | 23/ | 15/ 2 | 10/ 1 | 2/ 1 | 2/ | | / 3 | 1/ | | | | | | 276/ 8 |
| 102.5 | | 1/ | | 5/ | 3/ | 3/ | 9/ | 14/ | 26/ | 36/ | 12/ | 46/ | 22/ 1 | 23/ | 5/ 1 | 3/ 2 | 5/ | 1/ | 2/ 1 | | | | | | | | 216/ 5 |
| 100.5 | | | | 3/ | 2/ | | 11/ | 9/ | 19/ | 26/ | 22/ | 26/ | 10/ | 23/ | 7/ | 2/ | 1/ | | 1/ | | | | | | | | 162/ |
| 98.5 | | | 1/ | 2/ | 3/ | | 9/ | 8/ | 17/ | 11/ | 14/ | 19/ | 4/ | 5/ | 2/ | | 1/ | | 1/ 1 | | 1/ | | | | | | 98/ 1 |
| 96.5 | | | | 1/ | | 1/ | 2/ | 2/ | 5/ | 9/ | 9/ | 10/ | 4/ | 6/ | 4/ | | 1/ | | | | | | | | | | 54/ |
| 94.5 | | | 2/ | | SN | 2/ | 6/ | 2/ | 6/ | 6/ | 2/ | 6/ | 3/ | 4/ | 1/ | | | | | | | | | | | | 40/ |
| 92.5 | | | | | | | 2/ | 1/ | 5/ | 3/ | 1/ | 7/ | 2/ | 2/ | | | | | | | | | | | | | 23/ |
| 90.5 | 1/ | | | | | | | 1/ | | 3/ | 4/ | 1/ | 1/ | | 1/ | 1/ | | | | | | | | | | | 13/ |
| 88.5 | | | | | | | | 1/ | 1/ | | | | | | | | | | | | | | | | | | 2/ |
| 86.5 | | | | | | | | | | 1/ | | | | | | | | | | | | | | | | | 1/ |
| | 1 | 6 | 8 | 24 | 23 | 18 | 113 | 102 | 216 3 | 249 4 | 188 9 | 347 20 | 186 66 | 207 128 | 100 213 | 52 252 | 43 356 | 9 404 | 9 347 | 2 259 | 2 174 | 81 | 59 | 32 | 9 | 4 | 1905 2420 |

* Dimensional values are category midpoints expressed in millimeters.
Numerical entries in the table designate number of females/males in each category.

Sizing Categories

SN - Short Narrow
MN - Medium Narrow
MW - Medium Wide
LW - Long Wide

the bivariate table to encompass the maximum number of potential users for this distribution.

After the sizing categories are specified, the next step in the sequence is the development of the dimensional data for each sizing category. This procedure requires that all subjects within each of the sizing categories be treated as a sub-population and summary statistics prepared for each variable to be included in the analysis.

Referring again to Figure 9, the individuals who fall within each of the four sizing categories constitute a sub-group for developing the descriptive statistics that can be used as design data.

For convenience in working with these sizing categories, we will designate them as follows:

| | Sizing Category | Category Sample Size Male | Female | Ranges Included In Face Length | Face Breadth |
|---|---|---|---|---|---|
| 1. | Short Narrow | 3 | 829 | 90.5 - 106.5 | 114.5 - 134.5 |
| 2. | Medium Narrow | 119 | 704 | 106.5 - 122.5 | 114.5 - 134.5 |
| 3. | Medium Wide | 832 | 255 | 102.5 - 118.5 | 134.5 - 154.5 |
| 4. | Long Wide | 1379 | 17 | 118.5 - 134.5 | 134.5 - 154.5 |

It is unfortunate that the male and female data used in this analysis are from different anthropometric surveys and that the female series includes far fewer variables than are available in the male series. There are a sufficient number of comparable dimensions, however, to permit us to conduct a parallel sizing analysis on the two sets of data.

From the above outline of sizing categories, it is apparent that Category 1 (Short Narrow) is essentially a female category; that Category 2 (Medium Narrow) is mixed but predominantly female; Category 3 (Medium Wide) is also mixed but predominantly male; and Category 4 (Long Wide) essentially male in composition.

In the ideal situation where the data to be used are all from the same survey and having the same variables measured in exactly the same way, the best approach would be to pool the male-female data to determine appropriate design ranges. In the example above, the female data are, for our purpose, much less complete than the male data and will be used, therefore, only for Category 1 to supplement the more comprehensive data used in size Categories 2, 3, and 4.

The summary statistics of the mean and standard deviation (in parentheses), are given in Table 10 for each variable for each size category. These data are then used for the next step in our analysis to develop the design limits. These limits are given in Table 11. For the purpose of this illustration, the design limits have been established as the mean value plus or minus two standard deviations. These limits would include approximately 95 percent of all values for each of the variables in each sizing category. This would then specify the range of variability that a designer would strive to accommodate in each of the sizing categories. It will be noted that for a number of dimensions the variance is essentially the same for each of the sizing categories. This would indicate that these variables have

Table 10

Summary Statistics for Hypothetical
Face Length - Face Breadth Sizing Program
Mean (S.D.)*

| | Variable | Size Category 1 | Size Category 2 | Size Category 3 | Size Category 4 |
|---|---|---|---|---|---|
| 1. | Head Circ | 551(16) | 563(13) | 571(13) | 578(13) |
| 2. | Sagittal Arc | 345(15) | 344(17) | 345(17) | 348(17) |
| 3. | Min Frontal Arc | -- | 132( 8) | 135( 8) | 137( 8) |
| 4. | Bit-Coronal Arc | 336(14) | 348(12) | 355(12) | 360(12) |
| 5. | Bit-Min Front Arc | -- | 297( 9) | 306( 9) | 310( 9) |
| 6. | Bit-Subnasal Arc | -- | 282( 9) | 292( 9) | 295(10) |
| 7. | Bit-Menton Arc | -- | 313(10) | 324(11) | 329(12) |
| 8. | Bit-Submandibular | -- | 293(14) | 307(15) | 312(15) |
| 9. | Bit-Posterior Arc | -- | 289(15) | 292(14) | 296(15) |
| 10. | Head Length | 182( 6) | 197( 6) | 197( 6) | 200( 6) |
| 11. | Nasal Root Breadth | 13( 2) | 14( 2) | 15( 2) | 16( 2) |
| 12. | Ear Breadth | 30( 3) | 37( 3) | 38( 3) | 38( 3) |
| 13. | Ear Length | 52( 4) | 64( 4) | 65( 4) | 67( 4) |
| 14. | Ear Lth above Tragion | -- | 29( 3) | 29( 3) | 30( 3) |
| 15. | Head Breadth | 143( 5) | 150( 4) | 156( 5) | 157( 5) |
| 16. | Max Frontal Br | -- | 110( 4) | 116( 4) | 117( 4) |
| 17. | Bitragion Br | 127( 4) | 134( 4) | 142( 5) | 143( 5) |
| 18. | Face Breadth | 127( 4) | 132( 2) | 142( 4) | 143( 4) |
| 19. | Bigonial Br | 100( 5) | 110( 6) | 118( 7) | 118( 7) |
| 20. | Ear to Ear Br | -- | 181( 7) | 187( 8) | 190( 8) |
| 21. | Biocular Br | -- | 88( 5) | 91( 5) | 92( 5) |
| 22. | Interpupillary Br | -- | 60( 3) | 62( 3) | 63( 3) |
| 23. | Interocular Br | -- | 32( 2) | 33( 3) | 34( 3) |
| 24. | Nose Breadth | 32( 3) | 34( 3) | 35( 3) | 36( 3) |
| 25. | Lip Length | 43( 4) | 50( 4) | 52( 4) | 52( 4) |
| 26. | Ear Protrusion | -- | 21( 3) | 21( 3) | 21( 3) |
| 27. | Subnasale-Nasal Rt L | 44( 3) | 50( 3) | 49( 3) | 53( 3) |
| 28. | Philtrum | -- | 14( 2) | 15( 3) | 16( 3) |
| 29. | Lip to Lip Length | -- | 18( 4) | 16( 4) | 18( 4) |
| 30. | Menton to Subnasale L | 58( 4) | 66( 4) | 65( 4) | 71( 4) |
| 31. | Face Length | 102( 3) | 116( 4) | 114( 3) | 124( 4) |
| 32. | Glabella-Vertex | -- | 94(10) | 93(10) | 93(10) |
| 33. | Nasal Rt-Vertex | -- | 107(10) | 107( 9) | 108( 9) |
| 34. | X-Canthus-Vertex | 117( 8) | 119( 8) | 119( 7) | 120( 8) |
| 35. | Pronasale-Vertex | 146(12) | 147(12) | 146(11) | 149(11) |
| 36. | Subnasale-Vertex | 157(11) | 160(10) | 159(10) | 162(10) |
| 37. | Stomion-Vertex | 176(11) | 182(10) | 181(10) | 186(10) |
| 38. | Menton-Vertex | 215(10) | 224( 9) | 222( 9) | 231( 9) |
| 39. | Tragion-Vertex | 126( 8) | 133( 6) | 133( 6) | 135( 6) |
| 40. | Glabella to Wall | -- | 202( 6) | 202( 6) | 205( 7) |
| 41. | Nasal Rt to Wall | -- | 200( 6) | 200( 6) | 203( 6) |
| 42. | X-Canthus to Wall | -- | 177( 6) | 176( 6) | 179( 7) |
| 43. | Pronasale to Wall | 210( 9) | 225( 7) | 225( 7) | 228( 7) |
| 44. | Subnasale to Wall | 195(10) | 208( 8) | 208( 8) | 211( 8) |
| 45. | Lip Prom to Wall | 192(10) | 210( 8) | 210( 8) | 213( 9) |
| 46. | Menton to Wall | 182(11) | 201(10) | 204(10) | 205(10) |
| 47. | Tragion to Wall | 101( 9) | 104( 7) | 102( 6) | 104( 6) |

*Dimensions in millimeters

Table 11

Design Limits for Hypothetical
Face Length - Face Breadth Sizing Program
Mean (S.D.)*

| | Variable | Size Category 1 | Size Category 2 | Size Category 3 | Size Category 4 |
|---|---|---|---|---|---|
| 1. | Head Circ | 519-583 | 537-589 | 545-597 | 552-604 |
| 2. | Sagittal Arc | 315-375 | 310-378 | 311-329 | 314-382 |
| 3. | Min Frontal Arc | -- -- | 116-148 | 119-151 | 121-153 |
| 4. | Bit-Coronal Arc | 308-364 | 324-372 | 331-379 | 336-384 |
| 5. | Bit-Min Front Arc | -- -- | 279-315 | 288-324 | 292-328 |
| 6. | Bit-Subnasal Arc | -- -- | 264-300 | 274-310 | 275-315 |
| 7. | Bit-Menton Arc | -- -- | 293-333 | 303-346 | 305-353 |
| 8. | Bit-Submandibular | -- -- | 265-321 | 277-337 | 282-342 |
| 9. | Bit-Posterior Arc | -- -- | 259-319 | 264-320 | 266-326 |
| 10. | Head Length | 170-194 | 185-209 | 185-209 | 188-212 |
| 11. | Nasal Root Breadth | 9- 17 | 10- 18 | 11- 19 | 12- 20 |
| 12. | Ear Breadth | 24- 36 | 31- 43 | 32- 44 | 32- 44 |
| 13. | Ear Length | 44- 60 | 56- 72 | 57- 73 | 59- 75 |
| 14. | Ear Lth above Tragion | -- -- | 23- 35 | 23- 35 | 24- 36 |
| 15. | Head Breadth | 133-153 | 142-158 | 146-166 | 147-167 |
| 16. | Max Frontal Br | -- -- | 102-118 | 108-124 | 109-125 |
| 17. | Bitragion Br | 119-135 | 126-142 | 132-152 | 133-153 |
| 18. | Face Breadth | 114.5-134.5 | 114.5-134.5 | 134.5-154.5 | 134.5-154.5 |
| 19. | Bigonial Br | 90-110 | 98-122 | 104-132 | 104-132 |
| 20. | Ear to Ear Br | -- -- | 167-195 | 171-203 | 174-206 |
| 21. | Biocular Br | -- -- | 78- 98 | 81-101 | 82-102 |
| 22. | Interpupillary Br | -- -- | 54- 66 | 56- 68 | 57- 69 |
| 23. | Interocular Br | -- -- | 28- 36 | 27- 39 | 28- 40 |
| 24. | Nose Breadth | 26- 38 | 28- 40 | 29- 41 | 30- 42 |
| 25. | Lip Length | 35- 51 | 42- 58 | 44- 60 | 46- 60 |
| 26. | Ear Protrusion | -- -- | 15- 27 | 15- 27 | 15- 27 |
| 27. | Subnasale-Nasal Rt L | 38- 50 | 44- 56 | 43- 55 | 47- 59 |
| 28. | Philtrum | -- -- | 10- 18 | 9- 21 | 10- 22 |
| 29. | Lip to Lip Length | -- -- | 10- 26 | 8- 24 | 10- 26 |
| 30. | Menton-Subnasale L | 50- 66 | 58- 74 | 57- 73 | 63- 79 |
| 31. | Face Length | 90.5-106.5 | 106.5-122.5 | 102.5-118.5 | 118.5-134.5 |
| 32. | Glabella-Vertex | -- -- | 74-114 | 73-113 | 73-113 |
| 33. | Nasal Rt-Vertex | -- -- | 87-127 | 89-125 | 90-126 |
| 34. | X-Canthus-Vertex | 101-133 | 103-135 | 105-133 | 104-136 |
| 35. | Pronasale-Vertex | 122-170 | 123-171 | 124-168 | 127-171 |
| 36. | Subnasale-Vertex | 135-179 | 140-180 | 139-179 | 142-182 |
| 37. | Stomion-Vertex | 154-198 | 162-202 | 161-201 | 166-206 |
| 38. | Menton-Vertex | 195-235 | 206-242 | 204-240 | 213-249 |
| 39. | Tragion-Vertex | 110-142 | 121-145 | 121-145 | 123-147 |
| 40. | Glabella to Wall | -- -- | 190-214 | 190-214 | 191-219 |
| 41. | Nasal Root to Wall | -- -- | 188-212 | 188-212 | 191-215 |
| 42. | X-Canthus to Wall | -- -- | 165-189 | 164-188 | 165-193 |
| 43. | Pronasale to Wall | 192-228 | 211-239 | 211-239 | 214-242 |
| 44. | Subnasale to Wall | 175-215 | 192-224 | 192-224 | 195-227 |
| 45. | Lip Prom to Wall | 172-212 | 194-226 | 194-226 | 195-231 |
| 46. | Menton to Wall | 160-204 | 181-221 | 184-224 | 185-225 |
| 47. | Tragion to Wall | 83-119 | 90-118 | 90-114 | 92-116 |

*Dimensions in millimeters

a low level of relationship (correlation) with the key sizing dimensions and are not, therefore, effectively controlled in the sizing scheme. It is unfortunate that many dimensions of the head and face have a low level of relationship so that no single sizing scheme will exert a marked level of control. The variables that are of principal interest in respirator sizing and design have, however, been effectively reduced in variance within a size category by the use of the key dimensions of face length and face breadth.

The final step in this phase, the selection of the values that a designer of a facepiece will use, is dependent upon a number of considerations. The proper design value for the facepiece nose clearance will, of course, be based upon the upper limit value of nose protrusion, whereas proper value for the nasal root breadth will approach the lower limit value for each sizing category. The proper design value in each instance will depend upon what the designer envisions as the necessary interaction of the facepiece with the face to provide a comfortable leak-free fit.

After fabrication of the facepieces, a fit-test will indicate the success or failure of the previous steps in the design process. No matter how confident one may be in the analysis and treatment of the data, or in the logic of the design, positive proof exists only when the respirators are man-tested and found to provide the required degree of protection and comfort.

A recent paper entitled "Recommended Subject Selection and Test Procedure for Quantitative Respirator Testing at the NIOSH Testing and Certification Laboratory," (McConville et al., 1974) addresses specific aspects of sample selection and test procedure for use in man-testing of respirators.*

When the design of the facepieces has been proven, the final step is to estimate the tariff for production of each size of respirator. In general this would normally be a relatively straightforward utilization of the percentage of the total population that falls within each of the size categories. In reality, the lack of knowledge of the population of respirator users discourages the use of such a simple approach. We have no knowledge, for example, of the number of female workers in the labor force who might use respirators in their work. Until such data are developed, any such tariff estimates are largely guesses. In terms of male users, if we assume them to be distributed randomly with regard to face length-face breadth, the best such estimates based upon our hypothetical sizing scheme is:

| | Percent of Total Male Users |
|---|---|
| Size 1 | 0 |
| Size 2 | 5 |
| Size 3 | 36 |
| Size 4 | 59 |

* See also Hack et al., 1974.

With the completion of a tariff the major steps in the anthropometric design analysis are completed.

This discussion has been placed by necessity within the framework of a hypothetical four size respirator design program. However, the anthropometric design analysis that has been described and variations of this procedure have been used with considerable success in numerous personal protective equipment development programs over the past few years* and offer a considerable advantage over the older concepts of sizing and design.

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* See, for example, Emanuel et al., 1959; Ziegen et al., 1960; McConville et al., 1963; Alexander et al., 1964.

## Section III

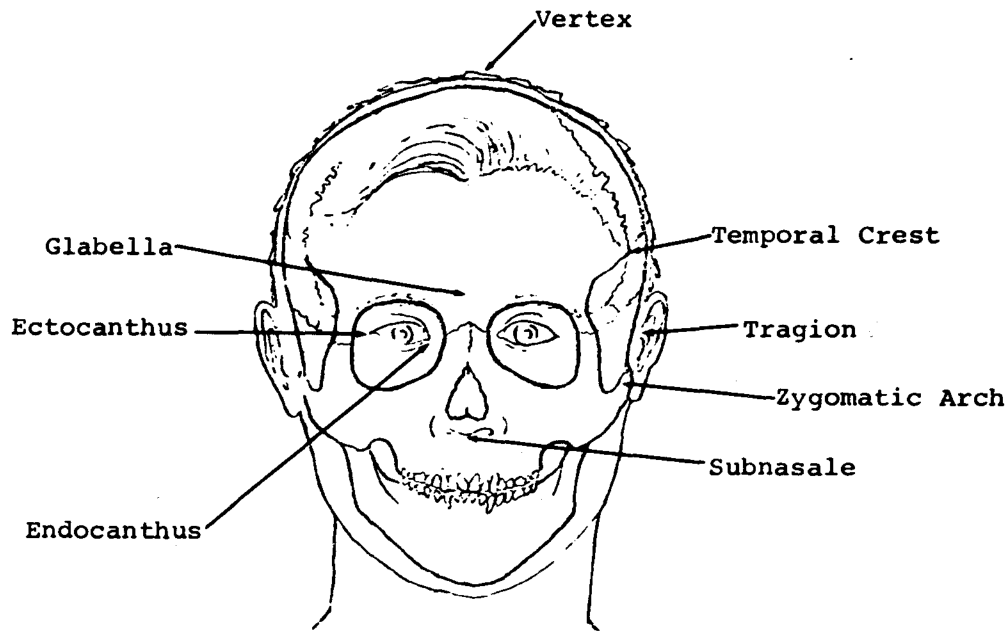
## SUMMARY AND CONCLUSIONS

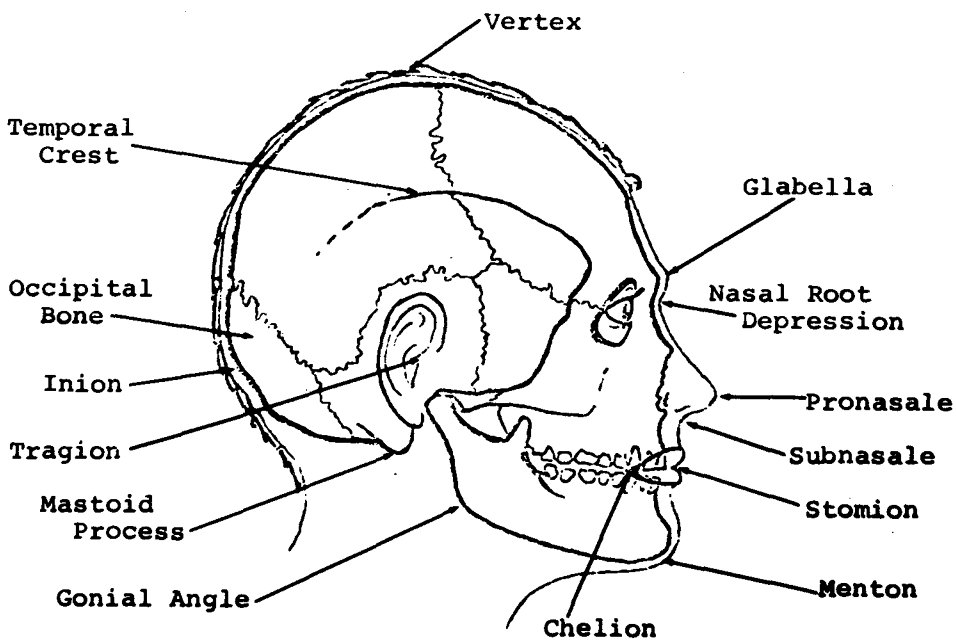
The range of physical variability in humans is broad and poses a continuing problem in the sizing and design of personal protective equipment such as respirators. The physical diversity of the facial region that must be accommodated in a successful respirator design is quantifiable and there exists a growing body of head and facial anthropometry available for use by designers. The best procedure for using such data in the development of design solutions, however, is not always clear.

A number of design and sizing concepts have been examined and their merits and weaknesses discussed. Significant problems associated with the concepts of the average man or percentile man in sizing studies are pointed out. A sizing and design concept and research procedure are recommended that are specifically related to the end item to be designed in terms of function and the range of variability in the user population that must be accommodated. While this concept is illustrated in terms of a hypothetical respirator sizing program, it is not a theoretical concept but one that has been used with success in many personal protective equipment designs and one which offers considerable advantages over previous concepts.

APPENDIX A

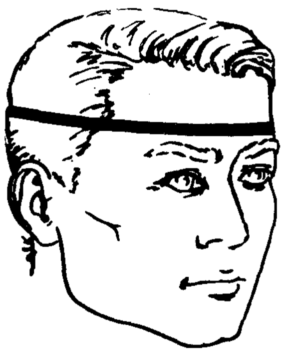
Landmarks of the Head and Face



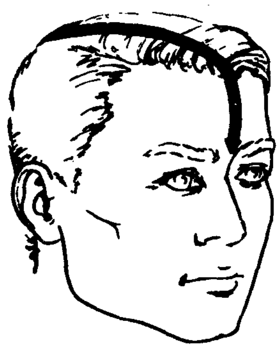



# APPENDIX B

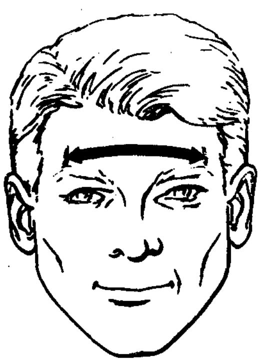
Description of Head and Face Measurements



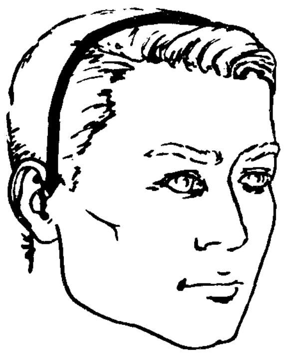
1. HEAD CIRCUMFERENCE: With a tape passing above (but not including) the brow ridges, measure the circumference of the head.



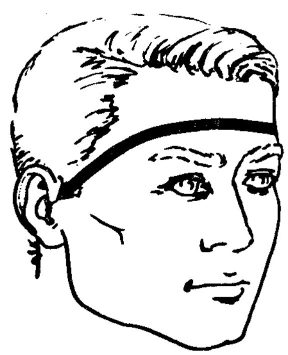
2. SAGITTAL ARC: With a tape held as close to the scalp as possible, measure the surface distance in the midsagittal plane from the glabella landmark on the forehead to the inion landmark on the occiput.



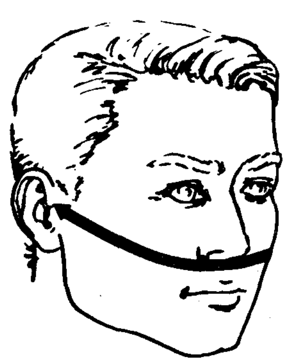
3. MINIMUM FRONTAL ARC: With the tape passing across the forehead between the points of greatest indentation medially of the temporal crests, measure the minimum arc across the forehead.



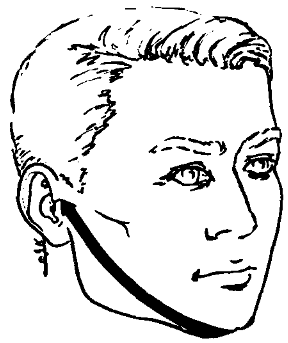
4. <u>BITRAGION-CORONAL ARC</u>: With a tape held as close to the scalp as possible, measure the surface distance in a coronal plane from the cartilaginous notch (tragion) just forward of the upper edge of the right ear hole to the corresponding tragion in the left ear.



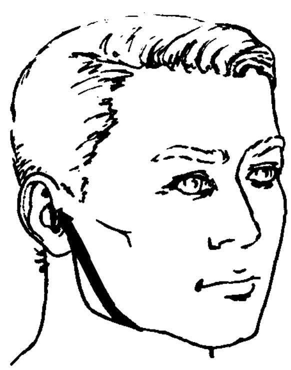
5. <u>BITRAGION-MINIMUM FRONTAL ARC</u>: With the tape passing over the region of the minimum frontal arc, measure the surface distance from the cartilaginous notch (tragion) just forward of the upper edge of the right ear hole to the corresponding tragion in the left ear.



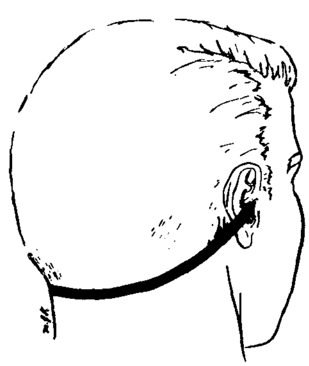
6. <u>BITRAGION-SUBNASAL ARC</u>: With the tape passing across the face and just below the nose, measure the arc from the cartilaginous notch (tragion) just forward of the upper edge of the right ear hole to the corresponding tragion in the left ear.



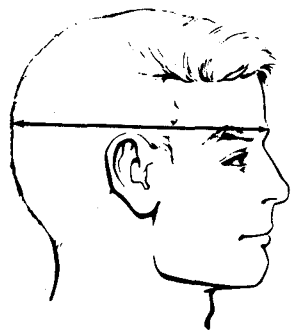
7. <u>BITRAGION-MENTON ARC</u>: With the tape passing over the tip of the chin (menton), measure the arc from the cartilaginous notch (tragion) just forward of the upper edge of the right ear hole to the corresponding tragion in the left ear.



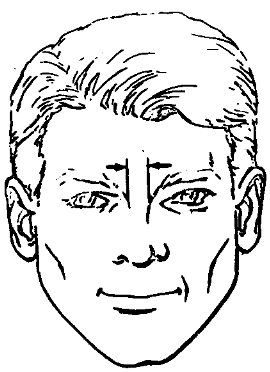
8. <u>BITRAGION-SUBMANDIBULAR ARC</u>: With the tape passing under the gonial angles of the jaw and along the juncture of the jaw and the neck, measure the arc from the cartilaginous notch (tragion) just forward of the upper edge of the right ear hole to the corresponding tragion in the left ear.



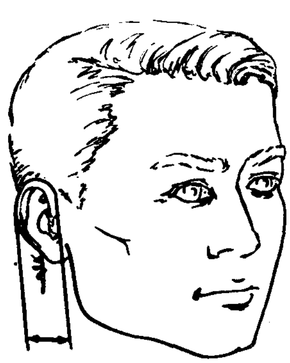
9. <u>BITRAGION-INION ARC</u>: With the tape passing over inion, measure the arc from the cartilaginous notch (tragion) just forward of the upper edge of the right ear hole to the corresponding tragion in the left ear.



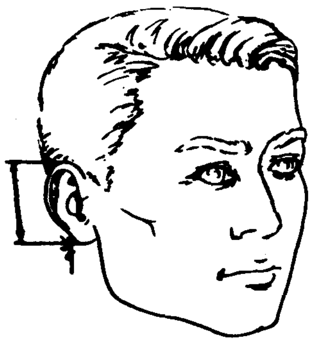
10. HEAD LENGTH: With a spreading caliper, measure in the midsagittal plane the maximum length of the head between the glabella landmark and the occiput.



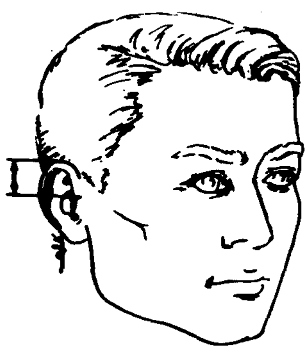
11. NASAL ROOT BREADTH: With the sliding caliper, measure the breadth of the nasal root.



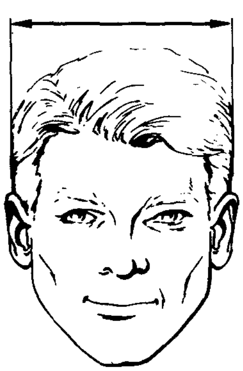
12. EAR BREADTH: With a sliding caliper, measure the maximum breadth of the right ear in a plane perpendicular to its major axis.



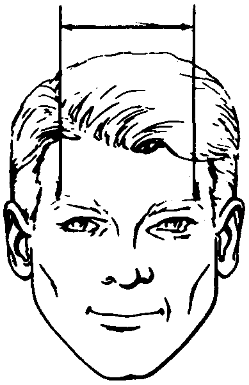
13. <u>EAR LENGTH</u>: With a sliding caliper, measure the maximum length of the right ear along its major axis.



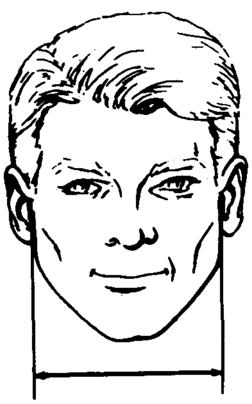
14. <u>EAR LENGTH ABOVE TRAGION</u>: With the bar of the sliding caliper held parallel to the long axis of the right ear, and one caliper arm passing over tragion, measure the distance to the top of the ear.



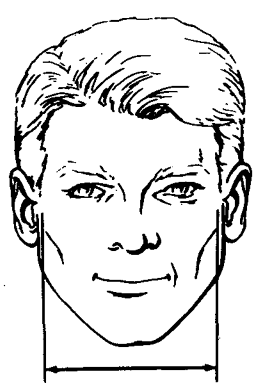
15. <u>HEAD BREADTH</u>: With a spreading caliper, measure the maximum horizontal breadth of the head in a line perpendicular to the midsagittal plane.



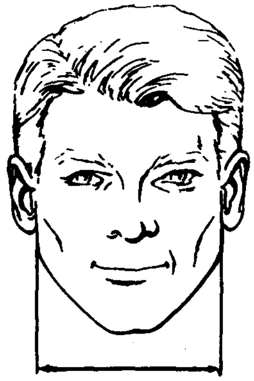
16. MAXIMUM FRONTAL BREADTH: With a spreading caliper, measure the horizontal distance between the maximum bulges of the brow ridges, at about the ends of the eyebrows.



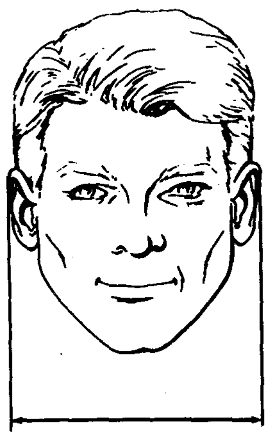
17. BITRAGION BREADTH: With a spreading caliper, measure the breadth of the head between the right tragion, the cartilaginous notch just forward of the upper edge of the right ear hole, and the corresponding tragion of the left ear.



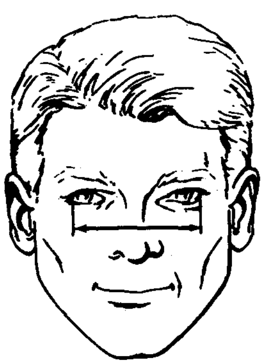
18. FACE BREADTH: With a spreading caliper, measure the maximum horizontal breadth of the face between the zygomatic arches, the most laterally projecting portions of the temporal bones.



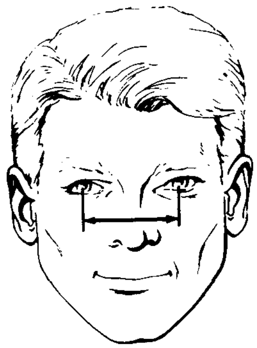
19. <u>BIGONIAL BREADTH</u>: With a spreading caliper, measure the maximum horizontal breadth of the jaw between the right and left gonial angles. Use minimum pressure in applying the caliper.



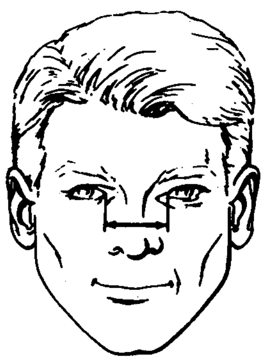
20. <u>EAR TO EAR BREADTH</u>: With a spreading caliper, measure the distance from the most lateral point of the right ear to the corresponding point of the left ear. Use minimum pressure in applying the caliper.



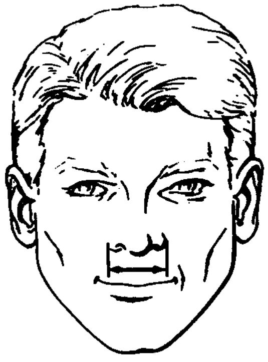
21. <u>BIOCULAR BREADTH</u>: With a sliding caliper, measure the breadth of the face between the right and left ectocanthus, the outer corners of the eyes.



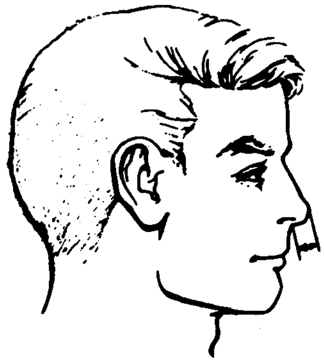
22. INTERPUPILLARY BREADTH: With a sliding caliper, measure the distance between the centers of the pupils.



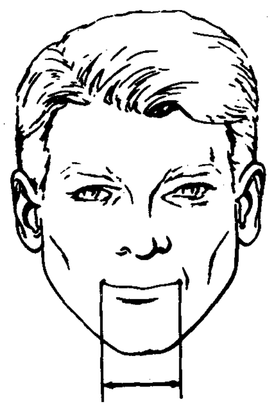
23. INTEROCULAR BREADTH: With the sliding caliper, measure the distance between the right and left endocanthus, the inner corners of the eyes.



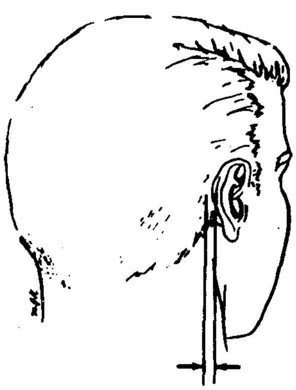
24. NOSE BREADTH: With a sliding caliper, measure the maximum horizontal breadth of the nose.



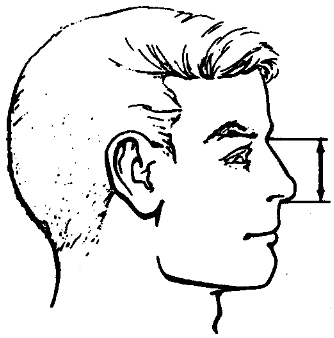
25. <u>NOSE PROTRUSION</u>: With the sliding caliper, measure the distance from the base of the septum to the maximum forward protrusion of the nose.



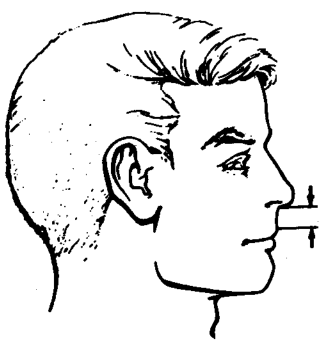
26. <u>LIP LENGTH</u>: Subject's facial muscles are relaxed and his jaws are closed. With a sliding caliper, measure the horizontal distance from the right to the left cheilion.



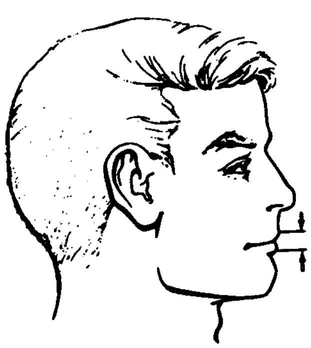
27. <u>EAR PROTRUSION</u>: With the sliding caliper, measure the distance from the mastoid process to the most lateral protrusion of the ear.



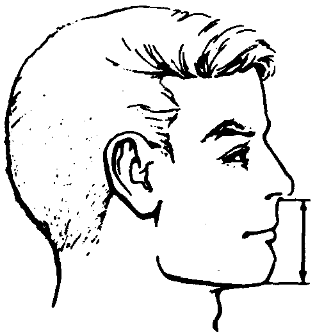
28. SUBNASALE-NASAL ROOT LENGTH: With a sliding caliper, measure the distance from subnasale to the deepest point of the nasal root depression.



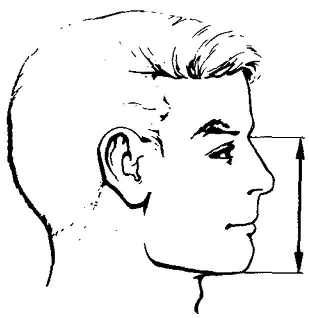
29. PHILTRUM LENGTH: Subject's facial muscles are relaxed and his jaws are closed. With the sliding caliper, measure the height of the groove (philtrum) which runs vertically from the edge of the upper membranous lip to subnasale.



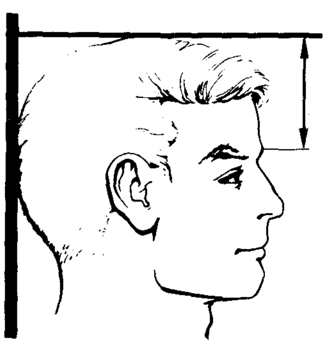
30. LIP TO LIP LENGTH: Subject's facial muscles are relaxed and his jaws closed. With the sliding caliper, measure the maximum distance between the lower margin of the lower lip and the upper margin of the upper lip.



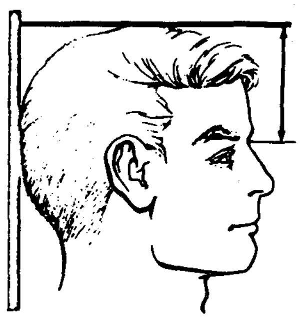
31. MENTON - SUBNASALE LENGTH: Subject's facial muscles are relaxed and his jaws are closed. With a sliding caliper, measure the distance from the menton landmark to subnasale.



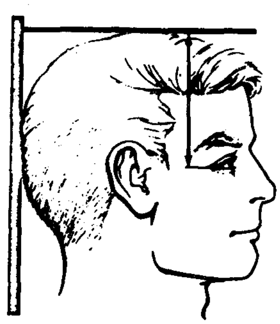
32. FACE LENGTH: Subject's facial muscles are relaxed and his jaws are closed. With a sliding caliper, measure the distance from the menton landmark to the deepest point of the nasal root depression.



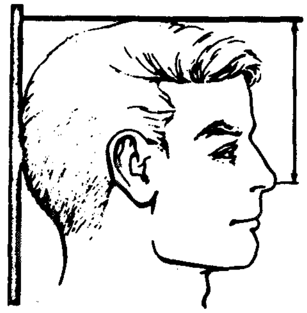
33. GLABELLA TO VERTEX: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is then adjusted so that its vertical and horizontal surfaces rest snugly against the back and top of the subject's head. Using the headboard gauge, measure the vertical distance from the glabella landmark to the horizontal plane.



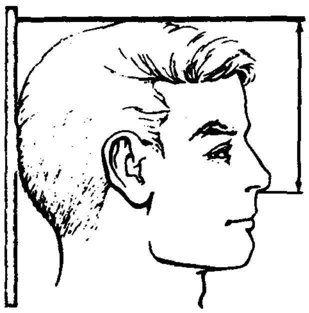
34. NASAL ROOT DEPRESSION TO VERTEX: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard slide is then adjusted so that its vertical and horizontal surfaces rest snugly against the back and top of the subject's head. Using the headboard gauge, measure the vertical distance from the deepest point of the nasal root depression to the horizontal plane.



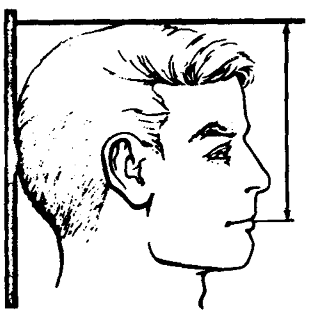
35. ECTOCANTHUS TO VERTEX: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the vertical distance from the right ectocanthus to the horizontal plane.



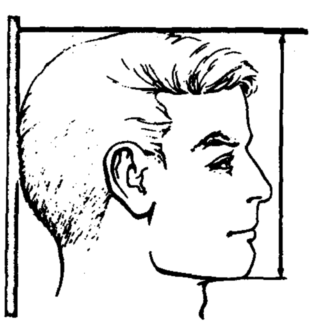
36. PRONASALE TO VERTEX: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the vertical distance from pronasale to the horizontal plane.



37. <u>SUBNASALE TO VERTEX</u>: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the vertical distance from subnasale to the horizontal plane.

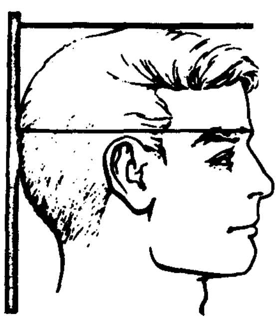


38. <u>STOMION TO VERTEX</u>: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the vertical distance from stomion, the point of contact betwen the lips, to the horizontal plane.

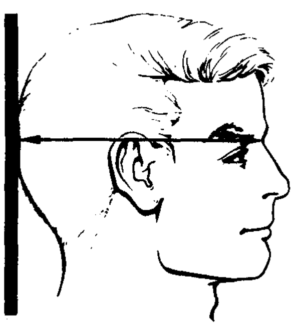


39. <u>MENTON TO VERTEX</u>: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the vertical distance from the menton landmark to the horizontal plane.

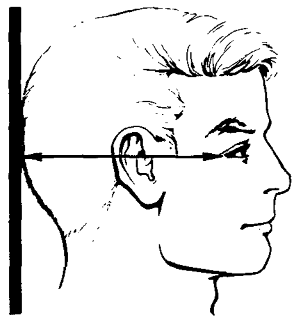
40. TRAGION TO VERTEX: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the vertical distance from the right tragion landmark to the horizontal plane.



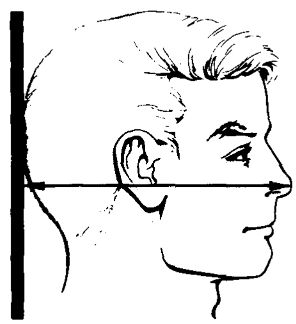
41. GLABELLA TO WALL: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from the glabella landmark to the vertical plane.



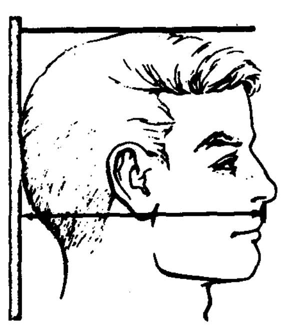
42. NASAL ROOT TO WALL: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from the nasal root depression to the vertical plane.



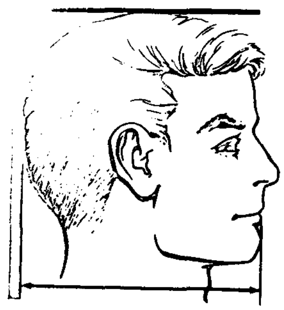
43. <u>ECTOCANTHUS TO WALL</u>: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from the right ectocanthus to the vertical plane.



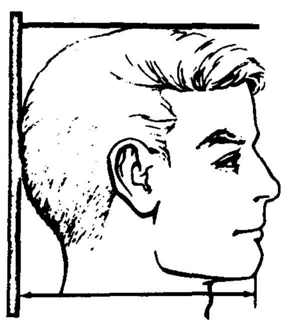
44. <u>PRONASALE TO WALL</u>: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from pronasale to the vertical plane.



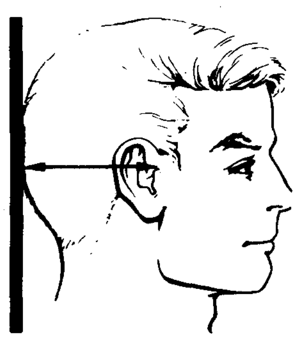
45. <u>SUBNASALE TO WALL</u>: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from subnasale to the vertical plane.



46. LIP PROMINENCE TO WALL: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from the lip prominence, the point of greatest anterior lip protrusion, to the vertical plane.



47. MENTON TO WALL: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from the menton landmark to the vertical plane.



48. TRAGION TO WALL: Subject stands under the headboard with his head oriented in the Frankfort plane. The headboard is adjusted so that its vertical and horizontal surfaces rest snugly against the back and the top of the subject's head. Using the headboard gauge, measure the horizontal distance from the right tragion landmark to the vertical plane.

49. AGE: Record as of last birthday.

50. HEIGHT: Subject stands erect, head in the Frankfort plane, heels together, and weight distributed equally on both feet. With the arm on the anthropometer firmly touching the scalp, measure the vertical distance from the standing surface to the top of the head.

51. WEIGHT: Subject stands on center of scale platform. Scale is read to the nearest pound.

## APPENDIX C

### GLOSSARY

BROW RIDGES - The bony ridges of the anterior forehead which lie above the orbits of the eyes.

CHEILION - The corners of the mouth formed by the juncture of the lips.

CORONAL PLANE - Any vertical plane at right angles to the midsagittal plane.

ECTOCANTHUS - The outside corner or angle formed by the meeting of the eyelids.

ENDOCANTHUS - The inside corner or angle formed by the meeting of the eyelids.

FRANKFORT PLANE - The standard horizontal plane or orientation of the head. The plane is established by a line passing through the right tragion and the lowest point of the right orbit (eye socket).

GLABELLA - The most anterior point of the forehead between the brow ridges in the midsagittal plane.

GONIAL ANGLE - The angle at the back of the lower jaw formed by the intersection of the vertical and horizontal portions of the jaw.

INION - Summit of the external occipital protuberance.

INTERPUPILLARY - Between the centers of the pupils of the eyes.

LIP PROMINENCE - Most anterior protrusion of either the upper or lower lip.

MASTOID PROCESS - A bony projection on the inferior lateral surface of the temporal bone behind the ear.

MENTON - The point of the inferior tip of the chin in the midsagittal plane.

MIDSAGITTAL - The vertical plane which divides the body into right and left halves.

NASAL ROOT DEPRESSION - The area of maximum indentation where the bridge of the nose meets the forehead.

OCCIPUT - A bone forming the posterior base of the skull.

OCULAR - Pertaining to the eyes.

PHILTRUM - Vertical groove which runs from the upper lip to subnasale.

PRONASALE - The most anterior point on the nose.

SAGITTAL - Pertaining to the anteroposterior median plane of the body.

SEPTUM - A dividing wall between two cavities, nasal septum; the fleshy partition between the two nasal cavities.

STOMION - The point of contact in the midsagittal plane between the upper and lower lips.

SUBMANDIBULAR - Below the mandible or lower jaw.

SUBNASALE - The point where the base of the nasal septum meets the philtrum (the groove in the upper lip).

TEMPORAL CREST - A narrow bony ridge along the side of the head above the ear level which serves as a point of attachment for the temporal muscles.

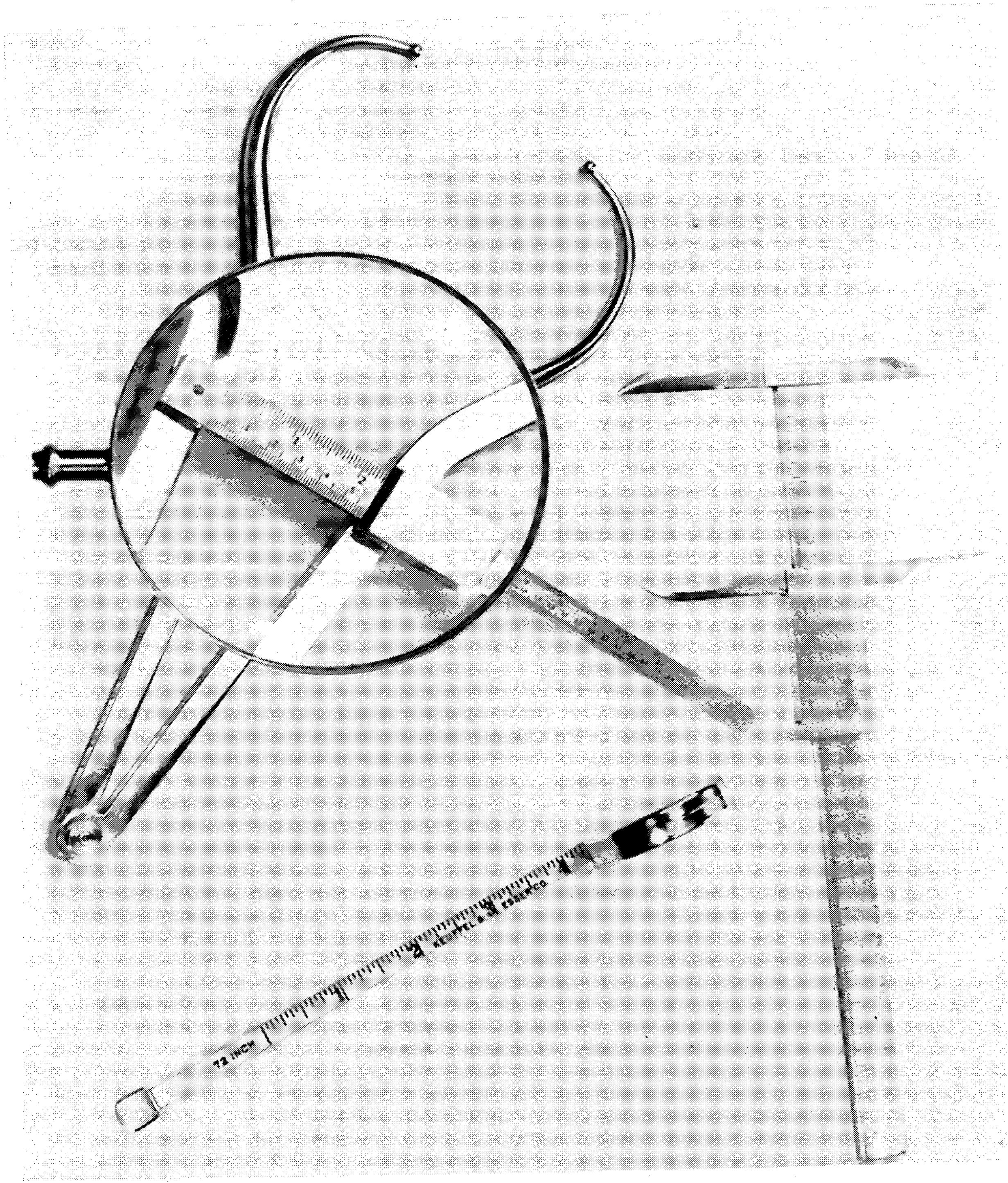
TRAGION - The point located at the notch just above the tragus of the ear.

VERTEX - Top of the head.

ZYGOMATIC ARCH - The bony arch extending horizontally along the side of the head from the cheekbone nearly to the external ear.

APPENDIX D

## Anthropometric Measurement Instruments




Instruments similar to those illustrated above are obtainable from a source such as:

Siber Precision, Inc.
450 Barell Avenue
Carlstadt, New Jersey 07072

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