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ANTHROPOMETRIC COMPARISONS BETWEEN *FACE MEASUREMENTS* OF MEN AND WOMEN (U)

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BIO-DYNAMICS CORPORATION

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FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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This report documents some of the differences in the body proportions of men and women in the region of the head and face. The study utilized discriminate analysis to pinpoint multivariate differences and regression analysis to indicate the magnitude of these differences from an applications' standpoint. The coefficients and estimates from these analyses are presented. It appears that for men and women who have the same facial breadth and length there are still considerable differences, particularly in the chin region. Consequently, it seems that for equipment designed to fit the face, sizes which are proportioned for men may not adequately fit women, even though the size may be small. It seems advisable to try to account for these differences at the design stage to ensure that both sexes are represented. This could reduce the number of sizes needed overall.

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PREFACE

This study was carried out under contract F33615-86-C-0547 with the Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Project scientists were Dr. Edward Schafer and Dr. Barry T. Bates, Bio-Dynamics Corporation. Ms. Kathleen M. Robinette, Human Engineering Division, Harry G. Armstrong Aerospace Medical Research Laboratory was contract monitor.

Mr. Shinwon Kim assisted in the computer analysis and construction of tables. Mr. Richard H. Tromel edited the report and coordinated resources needed to complete the work.

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INTRODUCTION

Since the Nation's armed forces include increasing numbers of female personnel, potential problems in the design and sizing of protective clothing and equipment have become apparent. These problems arise from the fact that most protective equipment and clothing now used by the armed forces were designed specifically for males. The improper fit of clothing and equipment can affect the safety, efficiency and productivity of personnel. Although fit is important for all apparel and equipment items, it is especially critical for those areas of design associated with the protection of the head and face.

In the past, most sizing and design of equipment relied on using three or four (small, medium, large, extra large) sizes which were proportionally scaled-up or scaled-down variants of an "average" person. The traditional size system assumes that measurements are, in general, proportional to each other. Thus, if one knows these proportions and knows, for instance, one of the key measurements, then the design technician has all the relevant size information necessary for adequate design. The extent to which the assumption of proportionality is invalid across groups results in a lower overall effective utilization of the equipment by large segments of the population.

More recently, an anthropometric sizing system was developed for oral-nasal oxygen masks (Alexander and McConville: 1979a). A four size system was designed based upon the key dimension of face length. Other critical dimensions were established as the regression mean values plus or minus a criterion standard deviation for the variable of interest. The system was designed and tested for male subjects only.

Recent studies (cf. McConville, Robinette and White: 1981) have documented the fact that anthropometric differences in body dimensions exist between genders which rule out the use of a "down-sized" male sizing system for females. The specific differences which preclude the "down-sizing" option are gender differences in proportionality among various measurements. The impact of differences of this type on head and face equipment is not fully documented.

In a preliminary study, selected head and face anthropometric differences between gender groups were analyzed and quantified. This was accomplished through a series of multivariate stepwise discriminant analyses on selected data taken from the 1977 survey of Army women. The discriminant analysis technique provides a description of the differences between two groups (females and males) on all relevant variables while taking into account the interrelationship among these variables. In addition, the analysis also provides information pertaining to how accurately subjects are classified (males and females) based on the variables selected.

In summary, all stepwise discriminant analyses for gender comparisons for the complete set and four variable subsets evaluated were significant ($p < 0.0001$). Individual classification success rates varied from 79.4 to 100.0% with canonical correlations coefficients averaging 0.766. Based upon these results, it was evident that differences between the sexes existed based upon the head and face parameters investigated.

Two possible solutions to the inadequacy of "down-sizing" male equipment for use by females are:

1) Separate sizing system for females based upon observed female face measurements

2) Single system that incorporates differences in variable proportions based upon the values of a few key dimensions.

While the first option will likely produce equipment with the best overall fit, the costs incurred in the production of two separate sets of items which meet the same functional need is something to be avoided if at all possible. The second option offers a compromise between the inadequacy of a "down-sized" male system and the redundancy of a separate sizing system for each gender group. However, if such a system is to work, research must be conducted to identify where differences in proportionality exist, and which, if any, key face dimensions can vary with these observed differences.

The purpose of this study was to identify differences in the proportionality among face dimensions between sexes which could affect the design and development of an adequate sizing system that will provide a high degree of proper fit of equipment for both male and female personnel. Specifically, this research report focused on those measurements that are known to be important in the design and sizing of protective face masks.

The methodology employed used multiple discriminant analysis and multiple regression techniques to help identify the differences in proportionality between genders. The discriminant analyses were used to identify key dimensions, i.e., face measures which show the greatest proportional differences between sexes; while multiple regression was used to estimate the relationships between the key dimensions identified and other variables important to the proper fit of protective face masks.

In summary, 19 of the 27 mean parameter values were significantly ($p < 0.05$) greater for the males compared to one for the females. No differences were found for the vertex measurements relative to the nose and eyes (ectocanthus, sellion, pronasale and subnasale), interpupillary distance, glabella-tragion and ectocanthus-tragion. Overall, 72.5% of the zero-order correlation coefficients were significantly ($p < 0.05$) different from zero while only 9.7% were greater than 0.71. In general, vertex measures correlated highly with each other as did tragion measures accounting for the majority (91.2%) of the correlations greater than 0.71. Similar results were observed between gender groups.

The results of the discriminant analyses indicated significant divergence from cross-gender anthropometric proportionality. Eleven (40.7%) and 13 (48.1%) variables entered the non-forced and forced models, respectively, with three standardized coefficients greater than 0.500 in each model and two and three negative coefficients, respectively. Overall, the women exhibited proportionality greater interpupillary and pronasale distances and shorter distances for all other measurements. An average canonical correlation coefficient of 0.82 and a 93.3% mean classification success rate were obtained. Males were misclassified more often than females (8.3 vs 4.8%) and the distribution of the misclassified individuals within the overlap region tended to be variable specific.

The results of the regression analyses further supported the lack of cross-gender proportionality. For those models using sellion-menton and face breadth as the independent variables, the cross-gender interactions occurred with face breadth. The effect was distributed across all the head and face dimensions although its impact was greatest on the vertex and tragion distances. For the second model (bitragion-submandibular arc and sellion-menton) the sex interactions involved the sellion-menton distance and the variables associated with vertex distances and facial breadths. In general, neither model produced very accurate results especially in the overlap regions of the male and female data sets.

This final report is divided into three chapters. Chapter I contains a brief review of selected reports to give the reader background information. Chapter II includes a discussion of the analytical procedures used to evaluate the data and Chapter III contains the results of the analysis along with a discussion of the findings.

CHAPTER I
BACKGROUND

This chapter contains a review of selected literature in order to provide the reader with background information. The review of anthropometric literature presented is divided into two anthropometric areas: a) head and face and b) sex related. Since these areas are not mutually exclusive some reports are included in both sections.

Head and Face Anthropometry

A number of different measurement techniques have been used during the course of the past 35 years to evaluate the anthropometric characteristics of the human head and face. Hursch (1976) described the historical development of the techniques used to study cranial form. Some of the measurement techniques which have been used include simple distances, angles and indices, surface determining methods, full surface or volume methods and holography. Once the measurements have been obtained, the results have been subjected to a number of analytical techniques including both univariate and multivariate analysis. The primary method used to date, however, has been the simple measurement technique, and it is upon this technique that most of the research presented is based.

The basic purpose for most of the studies, as they relate to the present study, has been the design of head and facial equipment and clothing for military and civilian populations. Damon, Stoudt and McFarland (1971) published a designer's handbook relating anthropometric information on the human body to the design of equipment. The handbook provides information on several head and face measurements, including head length, head breadth and interpupillary distance, and described the relevance of their measurements to equipment, clothing and workspace for both men and women.

One of the early studies done by Churchill and Daniels (1953) used data from a 1950 survey of over 4000 Air Force flying personnel to evaluate head and face anthropometry. Variable definitions, regression equations and standard errors are provided in the report. The results include nomograms for estimating each of 12 head dimensions based on known values of head length and head breadth, and head breadth and head circumference.

Along similar lines, a study conducted by Alexander, Zeigen and Emanuel (1961) presents three-dimensional representations of head and face data. Statistical sizing systems are established on the basis of key dimensions of total face length and lip length. The headform series, as a basis for helmet sizing, was based on the single key dimension of head circumference.

More recently other researchers have also studied the design of helmets and face masks. McConville and Clauser (1977) found, as did Alexander et al. (1961), that the most appropriate sizing dimension for helmets was head circumference. The authors compared the head and face anthropometry of different ASCC nations in relation to helmet design. When viewed against the variability of any single sample, the differences in head dimensions between the various groups were relatively small.

In another study related to the sizing of oxygen masks, Alexander and McConville (1979a) analyzed 36 head and face measurements from the 1967 survey of USAF men. A description of the steps involved in the process of completing the anthropometric sizing analysis is included. In general, the findings indicate that face dimensions have a relatively low correlation with each other. These results are similar to the results presented in a previous study by Tebbetts, Churchill & McConville (1980). Regression equations were used to evaluate the proportions of upper and lower face length. The results indicated that four sizes of masks were sufficient to cover the USAF male flying population. Similar to the findings in the earlier study (Alexander et al. 1961) face length, or, more specifically, the menton-nasal root length, was found to be the key dimension for the sizing of face masks. This dimension was the only one used as a sizing criterion for mask design. In addition, the breadth of the face-piece was based on two key dimensions: bizygomatic breadth and bigonial breadth.

A more recent pool of data including measurements on the head and face of females was provided by McConville, Churchill, Churchill and White (1977). The authors reported the results of a measurement study involving 1331 women and 287 men for the U.S. Army. The results are contained in a series of reports. Subseries C includes the head and face measurements taken, while subseries A includes the measurements of head length, head breadth and head circumference. In addition to the three basic head measurements, 34 head and face measurements were made on a subset of 102 men. The data from this report are being used in the present study.

As part of a study on anthropometry of the U.S. Army personnel, Tebbetts et al. (1980) measured head and face variables on male subjects of which approximately three-fourths were white, one-fourth black, and two percent oriental. Of interest to designers is their finding, based on an evaluation of correlation coefficients, that not only do the head and face measurements have a poor relationship to each other but they also have little relationship to other body measurements.

In addition to the work concerning head and face measurement done by the military, research has been carried out in other areas such as physical anthropology. One study (DeVilliers, 1968) was based on research involving the skull of the South African Negro. In general sexual differences were found to be significant. The male skull was found to be larger in nearly all dimensions compared to the female skull, with significant differences observed in all but five cases out of 51 dimensions. The sexual dimorphism of the skull of the South African Negro was associated mainly with the mandible, while the sexual differences in the shape of the skull were less pronounced and reflected the infantile characteristics of the female skull. The most significant sex differences were found to be the height of the mandibular ramus, breadth of the face, and, to a lesser degree, length and height of the cranial vault. Many cranial indices do not distinguish between females and males, rather, the sexual differences are reflected in the mandibular indices.

In summary, anthropometric study has been carried out on measurements of the head and face on both men and women, and on individuals of different racial heritage. Much of the work has been conducted by the military, with the intention of designing equipment such as helmets and face masks. In general, the results indicate that much variability exists within a given population with regard to head and face measurements.

Sex Related Anthropometry

Much of the early work involving sex related anthropometry has been conducted on civilian populations. Studies by O'Brien (1930) and O'Brien and Shelton (1941) as well as those by the early physical educators (Gould, 1930; Jorgenson and Hatlestad, 1940) included female populations in their investigations. These studies were concerned with total body anthropometric data rather than head and face data. Some differences were found to exist between males and females in terms of body dimensions.

Other more recent work in the area of sexual dimorphism has been completed by physical anthropologists. De Villiers (1968) studied the skulls of South African Negroes. Significant sex differences were found. The results indicated that the male skull was larger in 46 out of the 51 dimensions measured. The sexual dimorphism of the skull of the South African Negro was found to be associated mainly with the mandible. Many cranial indices did not distinguish between males and females, but rather sexual differences were reflected in the mandibular indices. The most significant sex differences were: height of the mandibular ramus, breadth of the face, and, to a lesser degree, length and height of the cranial vault. Sex differences in the shape of the skull were found to be less pronounced, and reflective of the infantile characteristics of the female skull.

Factor analysis and discriminant function analysis were employed by Choi and Trotter (1975) in a study of race-sex differences among fetal skeletons. Twenty-one measurements on each of 115 American white and Negro fetal skeletons were evaluated. The result indicated that the factor patterns of race-sex groups were similar. The discriminant analysis results showed that differences between the sexes were more marked than those between different races. The authors concluded that possible race and sex differences are less discernable among fetal skeletons than adult skeletons.

Bleibtreu and Taylor (1976) also used multivariate techniques (discriminant function analysis and canonical analysis) to categorize sexual dimorphism and racial groups. Boys and girls of four ethnic groups (N = 637) were studied. Previous results in this area have indicated that the "best" metric predictors differ among ethnic groups of the same chronological age. The results of this study indicated that the most important sex discriminators for children were limb joint diameters and dimensions of the head and face (except for the American Indians). Head and face measures were found to be the only important linear measurements.

In the sex-related anthropometric literature on military populations in the United States, the investigation reported by Churchill and Bernhardi (1957) on Women's Air Force (WAF) basic trainees served as a supplement to an original report in 1952 on WAF trainees. Based on 61 body dimension measurements, 1830 correlation coefficient pairings were obtained. Regression equations were provided for estimating all other dimensions.

Laubach, McConville, Churchill and White (1977) reported information from the first anthropometric survey of United States Army females in 30 years, involving 128 measurements on body size dimensions, 9 measurements of static strength, and 14 workspace dimensions. T! purpose of the study was to obtain and develop statistical data on female static muscle strength. The ultimate goal was to aid in the design of clothing, protective equipment, and workspace and industrial equipment. The first report in the series described the methodology involved, including landmarks used and procedures involved. The total series of measurements was divided into five separate groups. First, the core series included all subject and 69 conventional body size measurements. Each of the remaining four series included one-fourth of the subjects. Subseries 1 included approximately 24 additional conventional measures and several skinfold measurements. Subseries 2 involved 14 workspace measurements, while Subseries 3 included 31 head and face measurements. Subseries 4 involved nine strength measurements.

Another report on the results from an anthropometric survey of Army men and women was provided by McConville, Churchill, Churchill and White (1977). This survey involved 1331 United States Army women and 287 men. Subseries A included measurements of length, breadth and circumference of the head, while subseries C included head and face measurements.

One of the purposes for these extensive surveys is for the design of clothing and equipment for military men and women. Robinette, Churchill and McConville (1979) attempted to document true differences in body size and proportions between USAF men and women in relation to current design or changes in design. The data base used was the 1977 Army survey (McConville, Churchill, Churchill and White, 1977) of females and males. Fifty-six measurements were compared and evaluated with regard to the investigation of two main assumptions: 1) female body size can be represented by scaling down male body dimensions and 2) that males and females of approximately equal body weight and stature are approximately equal in all other proportions. The authors concluded that females cannot be represented accurately by scaling down male proportions and dimensions and that some height/weight samples indicate a degree of similarity between the sexes for selected dimensions. Among the dimensions which were the least reliable were those involving body tissue commonly associated with secondary sex characteristics (such as hip circumference, chest depth, and bicep circumference/flexed). Hand, foot and head dimensions were other subgroups that did not scale down satisfactorily for females or match the corresponding male values.

Alexander and McConville (1979b) presented a series of height/weight sizing programs used by designers of protective clothing for USAF men. The sizing values were based on an analysis of 1967 survey data involving 71 dimensions, excluding head, hand and foot measurements. The authors stated that, for the purposes of a general sizing program, the significant proportional differences between the sexes cannot be reconciled by the assumption that females require simply smaller scaled sizes of the same garments worn by men.

The report prepared by McConville, Robinette and White (1981) documented research leading to the development of an integrated male/female sizing system incorporating the body size data of persons of both sexes and taking into account the areas of disproportionality between them. The concepts underlying the development of a sizing system are presented along with the problems. The actual sizing programs developed are presented in a format usable for designers and pattern makers in a separate report (Robinette, Churchill & Tebbetts, 1981).

The approach used in the study (McConville, Robinette & White, 1981) was to identify key sizing variables that exert some level of control on variations of body size and proportionality found between the sexes for dimensions critical to the fit and function of the clothing item being sized. Stature and shoulder circumference were identified as the basis for sizing upper body garments. Crotch height and hip circumference were established as key dimensions for lower body unisex sizing programs. A system of 20 sizes was selected as adequate for both upper and lower body clothing systems.

In summary, literature in the area of sex differences in anthropometric measurements indicates that significant differences do exist between the sexes. These differences must be identified and used in the design of equipment, clothing and workspaces that are to be used by both men and women.

CHAPTER II
PROCEDURES

This chapter contains sample and variable descriptions along with a description of the primary procedures used in the data analysis.

Sample Description

The data for the analysis were acquired from the AFAMRL Anthropometric Data Bank Library: Volume IX, 1977 Survey of Army Women. The data were taken from the anthropometric survey conducted on U.S. Army women during the winter of 1976-77 at four Army bases under the U.S. Army Research & Development Command, Natick, Massachusetts. The results of this survey are reported in the Anthropometry of Women of the U.S. Army-1977 which was published in five reports identified in the bibliography. The data used in the present analysis were taken from the head and face subseries. Only the data for white subjects were used in the analysis resulting in 158 female and 72 male data sets.

Variable Description

The 27 descriptive parameters used in the analysis are identified in Table 1 and defined in Appendix A. These variables were all taken from the head and face sub-series measurements made on a sample of 216 females and 102 males. Only the data for the 158 white females and 72 white males were used in the present study.

Sixteen of the measurements provide vertical and horizontal coordinates relative to the top and back of the head. Five points on the profile are identified: menton, subnasale, pronasale, sellion (the deepest point in the nasal root depression), and glabella (a point on the forehead between the brow ridges), along with two non-profile points: ectocanthus (the outer corner of the eye) and tragion (the cartilaginous notch just forward of the ear hole). In addition, the vertical distance to the point of contact of the lips in the profile plane (stomion) and the horizontal distance to the most posterior point in the profile plane of either lip were measured.

Eight measurements are distances between points in the profile plane (sellion-menton, sellion-subnasale) or breadths across the face (biocular, interpupillary, nose, face, bitragion, and minimum frontal). Three measurements are arc lengths: measured from the right tragion to

Table 1. Variables Used in Face Mask Analysis

1. Sellion-Tragion
2. Subnasale-Tragion
3. Menton-Tragion
4. Glabella-Tragion
5. Pronasale-Tragion
6. Stomion-Tragion
7. Ectocanthus-Tragion
8. Bitragion-Frontal Arc
9. Bitragion-Menton Arc
10. Bitragion-Submandibular Arc
11. Tragion-Wall
12. Bitragion-Breadth
13. Tragion-Vertex
14. Ectocanthus-Vertex
15. Glabella-Vertex
16. Sellion-Vertex
17. Pronasale-Vertex
18. Subnasale-Vertex
19. Stomion-Vertex
20. Menton-Vertex
21. Sellion-Menton
22. Minimum-Frontal Breadth
23. Face Breadth
24. Biocular Breadth
25. Interpupillary Distance
26. Sellion-Subnasale
27. Nose Breadth

the left tragion with a tape which passed variously across the forehead (bitragion-frontal), under the chin (bitragion-menton), and under the jaw (bitragion-submandibular).

Discriminant Analysis

In a preliminary study, selected head and face anthropometric differences between gender groups were analyzed and quantified through a series of multivariate stepwise discriminant analyses on selected data taken from the 1977 survey of Army women. All estimated discriminant functions for gender comparisons were significant ($p < 0.0001$). For white subjects only, the standardized coefficients for the four primary overall head size measurements were -1.470 (circumference), 1.242 (length), -0.382 (menton-vertex) and 0.164 (breadth). A subset of similar variables and their corresponding coefficients obtained from the analysis included those measured from the vertex: tragion (-0.503), ectocanthus (1.196), glabella (-0.266), sellion (0.764), pronasale (-0.890), subnasale (-0.484), stomion (-0.402) and menton (-0.382). The differences noted among the signs of these similar measurements indicate a general lack of proportionality suggesting that a design based upon proportionality will be inadequate.

Multiple discriminant analysis is a particular procedure that is part of the general linear model. In the two-group situation (for example, males and females), this procedure is equivalent to multiple regression with a discrete variable having two levels (Kerlinger and Pedhazur; 1973: 377). The general form of the model is:

$$D_{ik} = d_{i1}z_{1k} + d_{i2}z_{2k} + \dots + d_{ip}z_{pk} \qquad \text{(EQ 1)}$$

where D_i is the score for the k-th individual on discriminant function i, the d's are the standardized discriminant coefficients and the z's are the p independent variables in standard form. Given that there are only two groups of individual cases (males or females), there is only one discriminant function and EQ 1 reduces to the form:

$$D_k = d_1z_{1k} + d_2z_{2k} + \dots + d_pz_{pk} \qquad \text{(EQ 2)}$$

Thus, the discriminant function for the two-group condition is little more than an estimated regression equation, with the only difference being the adjustment of the data for the group and total sample centroids or means (Nie, et al., 1975: 443).

The following basic assumptions about the statistical nature of the data are important for discriminant analysis:

1. All variables are measures on an interval or ratio scale.

2. Data cases must be assignable into one of two or more mutually exclusive groups.

3. Discriminating variables cannot be linear combinations of one or more other discriminating variables used in the analysis.

4. Equality must exist between the population covariance matrices.

5. Populations from which the samples are drawn are multivariate normal (Klecka, 1980: 8-10).

In this application of discriminant analysis, stepwise inclusion of variables was used to identify face measurements which demonstrate significant disproportionality across gender groups. In addition, the stepwise procedure provides insight as to the relative importance of each measurement compared to all other variables in the model with regard to cross-gender disproportionality. That is, variables which enter the model early are judged more disproportionate than those which enter the model late.

Two specific discriminant analyses were performed on the data set in this study. In the first analysis the two independent variables sellion-menton and face breadth were forced into the discriminant function first. After this initial step, all remaining variables were allowed to enter the model based upon a statistically significant ($p < 0.05$) Mahalanobis Distance (D^2). In the second analysis no variables were forced into the model and all variables were allowed to enter based upon the Mahalanobis Distance criteria used in the first application.

Regression Analysis

After identifying the most important variables in defining the disproportionality between males and females, the next step was to determine how these variables relate to other variables which are known to be important for the proper fit of face masks. This was accomplished using multiple regression analysis procedures to estimate two sets of regression equations. Sellion-menton and face breadth, and the two highest loading variables from the unforced discriminant analysis were used as the independent variable pairs. The dependent variable set for each of the two sets of regression equations consisted of all other variables used in the analysis.

The basic assumptions of multiple regression analysis are:

1. All variables are measured on an interval or ratio scale.

2. Relationships between the independent and dependent variables are linear.

3. Residuals are normally distributed with equal variances across the ranges of the independent variables.

4. Residuals are not correlated with the independent variables in the model.

5. Populations from which the samples are drawn are multivariate normal (Blalock, 1972: 386-389).

All regressions were estimated using two forms of the model. The first form is:

$$Y = a + b_1X_1 + b_2X_2 \qquad \text{(EQ 3)}$$

where Y is the dependent variable, the X's are the independent variables, the b's are the estimated partial regression coefficients and the a value is the intercept. This form of the model was estimated separately for the males and females. The second form of the model is:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 \qquad \text{(EQ 4)}$$

where Y is the dependent variable, X_1 and X_2 are the independent variables, X_3 is a dummy variable representing gender with males equal to 0 and females equal to 1, X_4 and X_5 are cross-product interaction terms between sex and X_1 and X_2, and a is the value of the intercept.

While Equation 3 is a predictive model, Equation 4 provides the information necessary to understand in what ways the structural relationships among various face dimensions vary across genders. Equation 5 is Equation 4 rewritten with comparable terms grouped:

$$Y = (a + b_3X_3) + (b_1X_1 + b_4X_4) + (b_2X_2 + b_5X_5) \qquad \text{(EQ 5)}$$

Given that X_3 can take the value of 0 or 1 and that X_4 and X_5 are the products of X_3 and X_1, and X_3 and X_2, respectively, when X_3 equals zero Equation 5 reduces to Equation 3 since all product terms of X_3 also become zero. Thus, the estimated values of b_3, b_4 and b_5 illustrate the differences between female and male estimated values of a, b_1 and b_2, respectively. Thus, a significant b_3 indicates that the intercepts are different across genders, even after the effects of the independent variables have been accounted for. However, a significant b_4 or b_5 implies a difference in the calculus between the independent and dependent variables across sexes. It is these differences that are of primary importance in this research.

In estimating both Equations 3 and 4 all relevant independent variables were allowed to enter the models simultaneously. Only the lack of sufficient tolerance precludes a variable from entering the model. In this application, a minimum tolerance level of 0.10 was used.

Equation 3 provides information as to the likely impact that differences between the sexes will have on the design and sizing of face masks. Male and female results were generated for each dependent variable for the various combinations of independent variables by inputting data values common to both males and females. The output of the male equation was then compared to the outcome of the female equation.

CHAPTER III
RESULTS AND CONCLUSIONS

This chapter contains the results of the analyses and an assessment of the likely impact that the findings will have on the proper design and fit of protective face equipment.

Descriptive Statistics

Table 2 contains the means and standard deviations for the total sample as well as for each gender group. Nineteen of the 27 mean values for males are statistically greater ($p < 0.05$) than the corresponding female values. The only female value that is statistically greater is the glabella-vertex distance. However, it is worth noting that no gender differences exist for the vertex measurements relative to the nose and eyes (ectocanthus, sellion, pronasale and subnasale). The remaining non-significant differences are for interpupillary distance, glabella-tragion and ectocanthus-tragion.

Tables 3, 4 and 5 contain the zero-order correlation coefficients for the male, female and total samples, respectively. An examination of these data indicates the presence of some multicollinearity. In each of the tables there are 351 cells. The numbers of coefficients significantly ($p < 0.05$) different from zero are 202 (57.5%), 267 (76.1%) and 295 (84.0%) for the male, female and total samples, respectively. Overall, only 9.7% of the coefficients have magnitudes equal to or greater than 0.71 indicating at least 50% common variance. The general pattern is for vertex measures (except for tragion-vertex) to correlate highly with each other (95.2% $\geq$ 0.71) as do the tragion measures (except for tragion wall) to a lesser extent (52.4% $\geq$ 0.71). The intercorrelations between these two subsets, however, are noticeably lower with all values being less than 0.50.

The presence of multicollinearity within the two blocks of variables noted above (vertex and tragion) could impact the analysis. With excessive multicollinearity, one of the basic problems of a stepwise procedure is that the order of entry into the model can be unstable across samples which come from the same population (Kachigan, 1982: 228).

The final aspect of the data contained in Tables 3, 4 and 5 is the reasonably similar results noted between genders. This is important since an assumption of discriminant analysis is

Table 2. Means and Standard Deviation of All Variables Used in the Face Mask Analysis

Variable	Male		Female		Difference of Means	Total	
	Mean	Std Dev	Mean	Std Dev	t-value	Mean	Std Dev
Sellion-Tragion	100.74	5.80	97.19	5.81	2.18 *	98.30	6.02
Subnasale-Tragion	106.13	5.71	101.75	5.82	6.03 *	103.12	6.12
Menton-Tragion	126.93	6.64	120.89	6.73	4.09 *	122.78	7.25
Glabella-Tragion	109.03	5.48	104.57	5.93	1.91	105.97	6.14
Pronasale-Tragion	120.12	5.94	115.34	6.23	5.50 *	116.84	6.52
Stomion-Tragion	109.74	6.34	105.32	5.82	5.43 *	106.70	6.32
Ectocanthus-Tragion	75.80	4.72	74.24	4.73	1.46	74.73	4.77
Bitragion-Frontal Arc	294.17	10.95	283.92	9.98	7.00 *	287.13	11.32
Bitragion-Menton Arc	309.04	11.94	291.18	12.43	10.23 *	296.77	14.80
Bitragion-Submandibular	285.42	12.62	264.07	13.51	11.34 *	270.75	16.52
Tragion-Wall	102.21	6.79	98.17	7.08	4.06 *	99.43	7.23
Bitragion Breadth	134.97	5.94	129.43	5.42	6.98 *	131.17	6.14
Tragion-Vertex	135.17	6.23	132.03	6.31	3.51 *	133.01	6.44
Ectocanthus-Vertex	111.86	7.36	110.76	7.41	1.05	111.10	7.39
Glabella-Vertex	81.14	7.98	84.27	8.18	2.71 *	83.29	8.23
Sellion-Vertex	98.04	9.94	99.75	8.71	1.32	99.21	9.13
Pronasale-Vertex	133.85	10.45	135.09	9.36	0.90	134.70	9.71
Subnasale-Vertex	147.24	8.98	147.60	8.77	0.29	147.49	8.82
Stomion Vertex	170.14	9.57	167.15	8.97	2.30 *	168.08	9.25
Menton-Vertex	214.51	10.00	207.53	9.39	5.12 *	209.72	10.10
Sellion Menton	116.76	7.02	106.56	5.50	11.93 *	109.76	7.65
Minimum-Frontal Breadth	111.35	8.44	104.96	5.02	7.14 *	106.96	6.94
Face Breadth	137.25	5.52	131.49	5.24	7.61 *	133.29	5.95
Biocular Breadth	100.25	4.92	94.80	4.57	8.18 *	96.51	5.31
Interpupillary Distance	58.33	4.64	57.26	4.14	1.76	57.60	4.32
Sellion-Subnasale	50.35	3.62	46.18	3.11	8.95 *	47.49	3.80
Nose Breadth	34.88	3.25	31.99	2.39	7.54 *	32.90	3.00
	N = 72		N = 158			N = 230	

Note: All measures are in millimeters.

* $p < 0.05$

Table 3. Correlation Matrix of Variables Used in Face Mask Analysis, Male Sample

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Sellion-Tragion	1.00																		
2. Subnasale-Tragion	0.77	1.00																	
3. Menton-Tragion	0.51	0.74	1.00																
4. Glabella-Tragion	0.89	0.68	0.33	1.00															
5. Pronasale-Tragion	0.82	0.92	0.62	0.74	1.00														
6. Stomion-Tragion	0.66	0.88	0.85	0.51	0.78	1.00													
7. Ectocanthus-Tragion	0.68	0.58	0.20	0.77	0.62	0.35	1.00												
8. Bitragion-Frontal Arc	0.55	0.44	0.33	0.62	0.47	0.39	0.48	1.00											
9. Bitragion-Menton Arc	0.44	0.51	0.70	0.38	0.49	0.60	0.25	0.63	1.00										
10. Bitragion-Submandibular Arc	0.15	0.24	0.39	0.12	0.23	0.31	0.04	0.41	0.72	1.00									
11. Tragion-Wall	-0.36	-0.42	-0.26	-0.30	-0.40	-0.36	-0.18	0.14	0.10	0.19	1.00								
12. Bitragion Breadth	0.10	-0.04	-0.03	0.04	0.01	0.03	-0.04	0.23	0.15	0.24	0.06	1.00							
13. Tragion-Vertex	0.41	0.04	-0.09	0.53	0.16	-0.03	0.33	0.54	0.30	0.26	0.13	0.17	1.00						
14. Ectocanthus-Vertex	0.20	0.03	0.03	0.27	0.06	0.06	0.18	0.31	0.26	0.35	-0.10	0.16	0.70	1.00					
15. Glabella-Vertex	0.05	0.01	0.09	0.05	-0.02	0.10	0.03	0.22	0.24	0.37	-0.09	0.16	0.50	0.87	1.00				
16. Sellion-Vertex	-0.04	-0.05	-0.07	0.08	-0.05	-0.08	0.20	0.14	0.12	0.30	-0.08	0.08	0.45	0.84	0.85	1.00			
17. Pronasale-Vertex	0.07	-0.00	0.06	0.13	0.01	0.04	0.18	0.25	0.25	0.37	-0.06	0.11	0.49	0.86	0.87	0.89	1.00		
18. Subnasale-Vertex	0.10	0.06	0.12	0.15	0.05	0.11	0.15	0.31	0.30	0.36	-0.10	0.07	0.51	0.87	0.89	0.85	0.97	1.00	
19. Stomion-Vertex	0.14	0.06	0.11	0.20	0.07	0.09	0.21	0.35	0.35	0.41	-0.04	0.13	0.55	0.87	0.84	0.86	0.96	0.96	1.00
20. Menton-Vertex	0.24	0.14	0.30	0.26	0.13	0.23	0.17	0.47	0.52	0.43	0.02	0.16	0.54	0.75	0.71	0.64	0.82	0.86	0.89
21. Sellion Menton	0.31	0.23	0.29	0.27	0.33	0.22	0.18	0.46	0.50	0.28	0.09	-0.03	0.27	0.11	0.04	-0.02	0.22	0.30	[illegible]
22. Minimum-Frontal Breadth	0.28	0.37	0.25	0.30	0.35	0.25	0.22	0.57	0.39	0.31	-0.06	-0.01	0.21	0.19	0.13	0.10	0.12	0.23	0.20
23. Face Breadth	0.27	0.24	0.16	0.26	0.26	0.22	0.18	0.58	0.39	0.37	0.01	0.67	0.26	0.20	0.21	0.15	0.20	0.23	0.25
24. Biocular Breadth	0.36	0.25	0.20	0.34	0.34	0.27	0.16	0.52	0.43	0.41	-0.16	0.31	0.45	0.38	0.28	0.22	0.33	0.35	0.40
25. Interpupillary Distance	0.32	0.30	0.24	0.35	0.36	0.21	0.23	0.50	0.40	0.27	-0.01	-0.14	0.34	0.18	0.11	0.08	0.09	0.16	0.15
26. Sellion-Subnasale	0.26	0.31	0.24	0.19	0.38	0.20	0.26	0.34	0.34	0.11	-0.02	-0.08	0.13	0.03	-0.03	-0.04	0.21	0.27	0.28
27. Nose Breadth	0.21	0.18	0.35	0.19	0.20	0.33	0.07	0.29	0.37	0.23	-0.11	0.29	0.20	0.26	0.29	0.17	0.23	0.26	0.26

Note: $p < 0.05$ for correlation coefficients of magnitude 0.23 or greater
N = 72

Table 3. Continued

Variable	20	21	22	23	24	25	26	27
1. Sellion-Tragion								
2. Subnasale-Tragion								
3. Menton-Tragion								
4. Glabella-Tragion								
5. Pronasale-Tragion								
6. Stomion-Tragion								
7. Ectocanthus-Tragion								
8. Bitragion-Frontal Arc								
9. Bitragion-Menton Arc								
10. Bitragion-Submandibular Arc								
11. Tragion-Wall								
12. Bitragion Breadth								
13. Tragion-Vertex								
14. Ectocanthus-Vertex								
15. Glabella-Vertex								
16. Sellion-Vertex								
17. Pronasale-Vertex								
18. Subnasale-Vertex								
19. Stomion-Vertex								
20. Menton-Vertex	1.00							
21. Sellion Menton	0.59	1.00						
22. Minimum-Frontal Breadth	0.24	0.37	1.00					
23. Face Breadth	0.33	0.32	0.61	1.00				
24. Biocular Breadth	0.43	0.45	0.47	0.54	1.00			
25. Interpupillary Distance	0.23	0.43	0.77	0.43	0.56	1.00		
26. Sellion-Subnasale	0.38	0.76	0.37	0.24	0.36	0.34	1.00	
27. Nose Breadth	0.31	-0.01	0.03	0.27	0.29	-0.01	-0.02	1.00

Note: $p < 0.05$ for correlation coefficients of magnitude 0.23 or greater
N = 72

Table 4. Correlation Matrix of Variables Used in Face Mask Analysis, Female Sample

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Sellion-Tragion	1.00																		
2. Subnasale-Tragion	0.81	1.00																	
3. Menton-Tragion	0.51	0.73	1.00																
4. Glabella-Tragion	0.94	0.73	0.44	1.00															
5. Pronasale-Tragion	0.86	0.95	0.67	0.80	1.00														
6. Stomion-Tragion	0.70	0.93	0.83	0.61	0.86	1.00													
7. Ectocanthus-Tragion	0.67	0.62	0.47	0.76	0.66	0.52	1.00												
8. Bitragion-Frontal Arc	0.56	0.43	0.44	0.55	0.48	0.45	0.47	1.00											
9. Bitragion-Menton Arc	0.34	0.43	0.71	0.32	0.40	0.55	0.36	0.54	1.00										
10. Bitragion-Submandibular Arc	0.28	0.33	0.51	0.29	0.34	0.43	0.34	0.45	0.73	1.00									
11. Tragion-Wall	-0.12	-0.18	-0.14	-0.15	-0.14	-0.12	-0.25	0.18	0.13	0.04	1.00								
12. Bitragion Breadth	0.24	0.27	0.42	0.25	0.29	0.32	0.38	0.46	0.55	0.59	-0.08	1.00							
13. Tragion-Vertex	0.33	0.04	-0.06	0.37	0.09	0.04	0.09	0.38	0.08	0.10	0.25	0.06	1.00						
14. Ectocanthus-Vertex	0.10	0.10	0.13	0.12	0.08	0.20	0.02	0.21	0.21	0.22	0.11	0.09	0.63	1.00					
15. Glabella-Vertex	0.02	0.09	0.16	-0.07	0.04	0.23	-0.12	0.20	0.22	0.20	0.21	0.09	0.50	0.88	1.00				
16. Sellion-Vertex	0.03	0.13	0.22	0.08	0.10	0.24	0.14	0.22	0.26	0.28	0.10	0.16	0.46	0.90	0.87	1.00			
17. Pronasale-Vertex	0.14	0.20	0.29	0.12	0.18	0.31	0.08	0.35	0.32	0.32	0.17	0.21	0.47	0.85	0.87	0.88	1.00		
18. Subnasale-Vertex	0.16	0.24	0.31	0.11	0.21	0.34	0.05	0.34	0.33	0.33	0.15	0.22	0.47	0.84	0.87	0.86	0.97	1.00	
19. Stomion-Vertex	0.18	0.24	0.32	0.16	0.22	0.36	0.13	0.34	0.34	0.38	0.15	0.22	0.49	0.85	0.83	0.87	0.93	0.95	1.00
20. Menton-Vertex	0.18	0.18	0.39	0.15	0.19	0.32	0.07	0.37	0.42	0.37	0.21	0.23	0.54	0.75	0.73	0.72	0.82	0.85	0.90
21. Sellion Menton	0.28	0.18	0.32	0.26	0.23	0.20	0.21	0.34	0.36	0.32	0.17	0.15	0.25	0.05	-0.01	0.01	0.19	0.22	0.33
22. Minimum-Frontal Breadth	0.15	0.11	0.20	0.15	0.15	0.19	0.14	0.51	0.43	0.42	0.13	0.33	0.26	0.27	0.26	0.26	0.27	0.26	0.27
23. Face Breadth	0.24	0.21	0.33	0.24	0.25	0.28	0.31	0.57	0.62	0.65	0.04	0.79	0.19	0.15	0.16	0.18	0.23	0.24	0.26
24. Biocular Breadth	0.21	0.16	0.19	0.20	0.18	0.23	0.09	0.51	0.32	0.32	0.18	0.29	0.16	0.07	0.10	0.09	0.14	0.14	0.18
25. Interpupillary Distance	0.12	0.10	0.16	0.11	0.13	0.18	0.06	0.34	0.27	0.27	0.16	0.13	0.23	0.17	0.22	0.18	0.19	0.21	0.24
26. Sellion-Subnasale	0.31	0.35	0.27	0.26	0.37	0.27	0.20	0.27	0.20	0.28	0.11	0.27	0.07	-0.05	-0.05	-0.07	0.26	0.29	0.26
27. Nose Breadth	0.13	0.16	0.34	0.14	0.17	0.30	0.17	0.27	0.39	0.33	0.03	0.24	0.16	0.22	0.25	0.28	0.28	0.29	0.34

Note: $p < 0.05$ for correlation coefficients of magnitude 0.16 or greater
N = 158

Table 4. Continued

Variable	20	21	22	23	24	25	26	27
1. Sellion-Tragion								
2. Subnasale-Tragion								
3. Menton-Tragion								
4. Glabella-Tragion								
5. Pronasale-Tragion								
6. Stomion-Tragion								
7. Ectocanthus-Tragion								
8. Bitragion-Frontal Arc								
9. Bitragion-Menton Arc								
10. Bitragion-Submandibular Arc								
11. Tragion-Wall								
12. Bitragion Breadth								
13. Tragion-Vertex								
14. Ectocanthus-Vertex								
15. Glabella-Vertex								
16. Sellion-Vertex								
17. Pronasale-Vertex								
18. Subnasale-Vertex								
19. Stomion-Vertex								
20. Menton-Vertex	1.00							
21. Sellion Menton	0.54	1.00						
22. Minimum-Frontal Breadth	0.27	0.19	1.00					
23. Face Breadth	0.28	0.25	0.63	1.00				
24. Biocular Breadth	0.19	0.17	0.53	0.48	1.00			
25. Interpupillary Distance	0.26	0.22	0.62	0.37	0.53	1.00		
26. Sellion-Subnasale	0.30	0.54	-0.04	0.17	0.09	-0.01	1.00	
27. Nose Breadth	0.36	0.15	0.28	0.32	0.29	0.27	0.04	1.00

Note: $p < 0.05$ for correlation coefficients of magnitude 0.16 or greater
$N = 158$

Table 5. Correlation Matrix of Variables Used in Face Mask Analysis, Total Sample

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Sellion-Tragion	1.00																		
2. Subnasale-Tragion	0.81	1.00																	
3. Menton-Tragion	0.56	0.77	1.00																
4. Glabella-Tragion	0.93	0.75	0.48	1.00															
5. Pronasale-Tragion	0.86	0.95	0.70	0.81	1.00														
6. Stomion-Tragion	0.71	0.92	0.85	0.62	0.85	1.00													
7. Ectocanthus-Tragion	0.68	0.61	0.41	0.76	0.65	0.48	1.00												
8. Bitragion-Frontal Arc	0.60	0.51	0.50	0.63	0.55	0.51	0.49	1.00											
9. Bitragion-Menton Arc	0.45	0.54	0.75	0.45	0.52	0.62	0.35	0.66	1.00										
10. Bitragion-Submandibular Arc	0.35	0.43	0.58	0.38	0.44	0.49	0.29	0.57	0.82	1.00									
11. Tragion-Wall	-0.11	-0.14	-0.06	-0.09	-0.11	-0.10	-0.18	0.25	0.24	0.22	1.00								
12. Bitragion Breadth	0.28	0.29	0.39	0.30	0.31	0.32	0.28	0.49	0.55	0.60	0.07	1.00							
13. Tragion-Vertex	0.39	0.11	0.02	0.46	0.18	0.09	0.19	0.48	0.25	0.25	0.26	0.18	1.00						
14. Ectocanthus-Vertex	0.15	0.10	0.12	0.18	0.09	0.17	0.08	0.25	0.22	0.25	0.07	0.13	0.65	1.00					
15. Glabella-Vertex	-0.02	0.00	0.06	-0.09	-0.04	0.12	-0.10	0.11	0.09	0.09	0.07	0.02	0.44	0.85	1.00				
16. Sellion-Vertex	-0.02	0.04	0.08	0.04	0.01	0.09	0.15	0.14	0.13	0.18	0.02	0.08	0.42	0.87	0.86	1.00			
17. Pronasale-Vertex	0.10	0.11	0.17	0.09	0.10	0.18	0.10	0.26	0.21	0.23	0.08	0.13	0.45	0.85	0.86	0.88	1.00		
18. Subnasale-Vertex	0.13	0.17	0.22	0.11	0.14	0.24	0.07	0.29	0.25	0.26	0.07	0.14	0.47	0.85	0.87	0.85	0.97	1.00	
19. Stomion-Vertex	0.20	0.22	0.29	0.21	0.21	0.30	0.17	0.37	0.37	0.40	0.12	0.24	0.53	0.85	0.78	0.84	0.92	0.94	1.00
20. Menton-Vertex	0.27	0.26	0.44	0.27	0.26	0.36	0.14	0.49	0.53	0.49	0.22	0.31	0.57	0.73	0.62	0.63	0.76	0.80	0.89
21. Sellion Menton	0.39	0.35	0.46	0.40	0.41	0.36	0.25	0.54	0.61	0.56	0.27	0.32	0.33	0.10	-0.10	-0.05	0.12	0.18	0.36
22. Minimum-Frontal Breadth	0.29	0.33	0.35	0.32	0.34	0.32	0.21	0.61	0.54	0.51	0.15	0.32	0.30	0.23	0.10	0.13	0.15	0.21	0.27
23. Face Breadth	0.34	0.34	0.40	0.36	0.36	0.37	0.31	0.66	0.66	0.67	0.14	0.80	0.29	0.18	0.08	0.11	0.17	0.20	0.29
24. Biocular Breadth	0.35	0.32	0.34	0.36	0.36	0.36	0.17	0.61	0.52	0.53	0.19	0.43	0.33	0.18	0.05	0.08	0.15	0.17	0.30
25. Interpupillary Distance	0.21	0.20	0.22	0.21	0.23	0.22	0.13	0.41	0.32	0.28	0.13	0.08	0.29	0.18	0.16	0.13	0.15	0.19	0.22
26. Sellion-Subnasale	0.38	0.44	0.40	0.36	0.48	0.37	0.26	0.45	0.46	0.46	0.19	0.33	0.19	0.01	-0.13	-0.09	0.18	0.23	0.31
27. Nose Breadth	0.26	0.29	0.45	0.28	0.31	0.41	0.18	0.41	0.53	0.47	0.10	0.40	0.25	0.24	0.15	0.17	0.21	0.24	0.34

Note: $p < 0.05$ for correlation coefficients of magnitude 0.13 or greater
N = 230

Table 5. Continued

Variable	20	21	22	23	24	25	26	27
1. Sellion-Tragion								
2. Subnasale-Tragion								
3. Menton-Tragion								
4. Glabella-Tragion								
5. Pronasale-Tragion								
6. Stomion-Tragion								
7. Ectocanthus-Tragion								
8. Bitragion-Frontal Arc								
9. Bitragion-Menton Arc								
10. Bitragion-Submandibular Arc								
11. Tragion-Wall								
12. Bitragion Breadth								
13. Tragion-Vertex								
14. Ectocanthus-Vertex								
15. Glabella-Vertex								
16. Sellion-Vertex								
17. Pronasale-Vertex								
18. Subnasale-Vertex								
19. Stomion-Vertex								
20. Menton-Vertex	1.00							
21. Sellion Menton	0.61	1.00						
22. Minimum-Frontal Breadth	0.35	0.45	1.00					
23. Face Breadth	0.40	0.47	0.68	1.00				
24. Biocular Breadth	0.38	0.49	0.59	0.61	1.00			
25. Interpupillary Distance	0.27	0.31	0.65	0.40	0.53	1.00		
26. Sellion-Subnasale	0.43	0.74	0.33	0.38	0.38	0.16	1.00	
27. Nose Breadth	0.43	0.34	0.31	0.44	0.44	0.19	0.24	1.00

Note: $p < 0.05$ for correlation coefficients of magnitude 0.13 or greater
$N = 230$

that the correlation between any two predictor variables must be similar within the respective populations (Kachigan, 1982: 219).

Discriminant Analyses

Tables 6 and 7 contain the results of the discriminant analyses for the model with no forced variables and the model in which sellion-menton distance and face breadth were the forced variables, respectively. Each table is divided into two panels. The top panel contains the step in which each variable entered the model, the standardized discriminant coefficient for each variable that met the criteria for entering the model, the overall canonical correlation coefficient and the proportion of correctly classified cases for the model. The step entered indicates the relative discriminating strength of each variable after adjusting for all variables previously entered into the model. For example, the results in Table 6 demonstrate that, as a single variable, sellion-menton distance has the greatest discriminating strength of all the variables used in the analysis. In addition, once differences in this variable have been accounted for, bitragion-submandibular arc contributes the next greatest degree of discriminating strength. This process is repeated until all variables meeting the criteria for inclusion in the model are entered.

The standardized discriminant coefficients reflect the relative strength and direction of the effect of each variable in the model after all variables meeting the inclusion criteria have been entered. Thus, while the sellion-menton distance has the greatest discriminating power by itself, when combined with the other variables in the model it is only the sixth most influential measure. When all variables are entered into the model, the pronasale-vertex distance becomes the most influential variable.

The model with no forced variables (Table 6) is the one to which the other model is compared. The first four variables to enter the model were sellion-menton, bitragion-submandibular arc, tragion-wall and ectocanthus-vertex. These measures include representative variables of the major dimensions that define the head and face, i.e., upper and lower head length (ectocanthus-vertex and sellion-menton), depth (tragion-wall) and breadth (bitragion-submandibular arc). The fact that representative measures of these various dimensions enter the model provides evidence that 1) there are differences in proportionality

Table 6. Discriminant Analysis of Selected Head and Face Measures With Gender as the Dependent Variable and No Variables Forced into the Model

Independent Variables	Step Entered	Standardized Discriminant Coefficient
Pronasale-Vertex	3	-1.569
Ectocanthus-Vertex	4	0.769
Interpupillary Distance	7	-0.521
Sellion-Subnasale	5	0.492
Sellion-Vertex	11	0.484
Sellion-Menton	1	0.389
Bitragion-Submandibular Arc	2	0.367
Face Breadth	6	0.307
Minimum-Frontal Breadth	10	0.251
Biocular Breadth	8	0.249
Tragion-Wall	9	0.200

Canonical Correlation = 0.810

Proportion Correctly Classified by Function

Males = 91.7%
Females = 93.7%

Table 6. Continued

Independent Variables	Structural Coefficient
Sellion-Menton	0.573
Bitragion-Submandibular Arc	0.544
Bitragion-Menton Arc	0.516
Face Breadth	0.447
Sellion-Subnasale	0.429
Bitragion-Frontal Arc	0.414
Biocular Breadth	0.393
Nose Breadth	0.362
Minimum-Frontal Breadth	0.343
Bitragion Breadth	0.321
Glabella-Tragion	0.306
Pronasale-Tragion	0.304
Menton-Tragion	0.297
Sellion-Tragion	0.291
Menton-Vertex	0.278
Stomion-Tragion	0.259
Tragion-Vertex	0.257
Subnasale-Tragion	0.246
Ectocanthus-Tragion	0.238
Tragion-Wall	0.195
Stomion-Vertex	0.132
Glabella-Vertex	-0.104
Interpupillary Distance	0.084
Sellion-Vertex	-0.063
Ectocanthus-Vertex	0.050
Pronasale-Vertex	-0.043
Subnasale-Vertex	0.015

Table 7. Discriminant Analysis of Selected Head and Face Measures With Gender as the Dependent Variable and Sellion-to-Menton Distance and Face Breadth Forced into the Model

Independent Variables	Step Entered	Standardized Discriminant Coefficient
Pronasale-Vertex	4	-1.518
Ectocanthus-Vertex	5	0.696
Interpupillary Distance	8	-0.501
Sellion-Vertex	12	0.494
Face Breadth	2	-0.488
Sellion-Subnasale	6	0.455
Minimum-Frontal Breadth	9	0.450
Sellion-Menton	1	0.430
Bitragion-Submandibular Arc	3	0.389
Bitragion Breadth	13	0.320
Nose Breadth	7	0.314
Biocular Breadth	10	0.270
Tragion-Wall	11	0.202

Canonical Correlation = 0.816

Proportion Correctly Classified by Function

Males = 91.7%
Females = 94.9%

Table 7. Continued

Independent Variables	Structural Coefficient
Sellion-Menton	0.560
Bitragion-Submandibular Arc	0.532
Bitragion-Menton Arc	0.503
Sellion-Subnasale	0.420
Bitragion-Frontal Arc	0.395
Biocular Breadth	0.384
Face Breadth	0.357
Nose Breadth	0.354
Minimum-Frontal Breadth	0.335
Bitragion Breadth	0.327
Menton-Tragion	0.320
Pronasale-Tragion	0.305
Glabella-Tragion	0.297
Sellion-Tragion	0.284
Menton-Vertex	0.277
Stomion-Tragion	0.263
Subnasale-Tragion	0.249
Tragion-Vertex	0.235
Ectocanthus-Tragion	0.228
Tragion-Wall	0.191
Stomion-Vertex	0.133
Glabella-Vertex	-0.110
Interpupillary Distance	0.082
Sellion-Vertex	-0.062
Ectocanthus-Vertex	0.049
Pronasal-Vertex	-0.042
Subnasale-Vertex	0.013

across genders, and 2) that this lack of inter-gender proportionality is not isolated to a single dimension, thus complicating the development of a single sizing and design system for head and face protective equipment.

In all, only eleven variables met the criteria for entry. It is interesting to note that only one arc measure (bitragion-submandibular arc), one tragion measure (tragion-wall) and three vertex measures (pronasale, ectocanthus and sellion) met the criterion for entry. This was probably due to the high intercorrelations within these subsets of variables.

Once all variables were entered in the model, the strengths of the first two variables entered (sellion-menton and bitragion-submandibular arc) diminished to sixth and seventh place with standardized discriminant coefficients of 0.389 and 0.367, respectively. The sign and the magnitude of the standardized discriminant coefficients are also important in understanding the manner in which the structure of the female head and face differs from that of males. For instance, in terms of net size, i.e., the relative size of a measurement once all other measurements in the model have been controlled, women have greater pronasale-vertex and interpupillary distances than do men. In addition, the effect of these differences is quite strong as indicated by the magnitudes of the standardized coefficients (-1.569 and -0.521).

The results of the discriminant analysis also indicate a lack of inter-gender proportionality within the vertex dimension of head structure. Thus, while the analysis indicates that the vertex dimension of males is greater than that of females, the proportional distance between the points pronasale and ectocanthus, controlling for all other variables in the model, is greater for females than for males.

The combination of the cross-gender differences noted above and the sign and magnitude of the standardized discriminant coefficient for interpupillary distance indicates differences between sexes in the location of the eyes relative to other head and face landmarks. These differences must be accounted for when designing sizing systems for head and face protective equipment.

The canonical correlation coefficient and proportion correctly classified are measures of the adequacy of the overall discriminant function. As previously mentioned, when applying discriminant analysis to a two group situation, the procedure becomes analogous to multiple regression with a dichotomous dependent variable. The canonical correlation coefficient, in this case, is nothing more than the multiple regression correlation coefficient.

The proportion correctly classified by the function indicates the percent of all cases in the sample that would have been correctly classified by gender from the function if the actual sexes of the cases were unknown. Obviously, this has little practical application in this study other than as a measure of the power of the function. The overall model appears to have reasonably good discriminating power with an average of 92.7% of all cases being correctly classified and a canonical correlation coefficient of 0.81.

The bottom panel of Table 6 contains the structural coefficients. These represent the zero-order correlation coefficients between the independent variables and the estimated discriminant scores for each subject in the sample. Thus, they provide information as to how each variable relates to the overall estimated discriminant function.

A review of the structural coefficients in Table 6 indicates that the estimated discriminant function is not highly correlated with any particular variable. The highest coefficient is 0.573. Thus, less than a third of the total variance of the discriminant scores is shared by any one variable. Yet, there appears to be some general ordering of shared variation between the discriminant scores and major groups of variables. For instance, the most highly correlated group of measures with the discriminant function contains variables which relate to the size of the lower part of the face (sellion distances), followed by breadth measures, then tragion measures and, lastly, vertex measures.

Table 7 contains the results of the discriminant analysis where sellion-menton distance and face breadth were forced into the model as the first two independent variables. A comparison of these data with the Table 6 results reveals some notable differences between the two. Two additional variables entered into the model (bitragion breadth and face breadth) with standardized coefficients of 0.320 and -0.488, respectively. Minimum-frontal breadth makes a greater contribution (0.251 to 0.450) than in the preceding analysis. Only minor differences between the performances of the two models were observed. The second model has a canonical correlation coefficient of 0.82 compared to 0.81 and the proportions correctly classified by the estimated functions were similar (93.3 vs 92.7%). Finally, a comparison of the structural coefficients between the two models indicates a considerable similarity in the mathematical structure of the two estimated discriminant functions. This is evident by the fact that the structural coefficients (the zero-order correlations coefficients between each independent variable and the estimated factor scores) are similar across the two models with differences ranging from 0.001 to 0.023 with a mean difference of only 0.008.

Overall, the results of the discriminant analyses indicate significant divergence from cross-gender anthropometric proportionality. For example, if there was perfect proportionality, only one variable would ever enter the discriminant function since all other variables would be mathematical transformations of that one variable. However, in these models, 11 and 13 variables entered, with coefficients greater than 0.500 for three of the variables in each model. In addition, the signs associated with each coefficient give the direction of the disproportionality. For example, after controlling for all other variables women are likely to have proportionately greater interpupillary and pronasale distances and shorter distances for all other measurements.

Bivariate Distribution Plots

Figures 1 through 4 contain gender-specific bivariate distribution plots for 1) sellion-menton distance by bitragion-submandibular arc and 2) sellion-menton distance by face breadth. Each plot indicates the location of the male or female sub-samples across the two selected variables. In addition, those subjects incorrectly classified by one or more of the functions are indicated with an "X".

A cross-gender comparison of the distribution of cases within each bivariate plot conforms to what one would expect given the sex differences in the mean values of the three variables used in the plots.

For all three variables (sellion-menton, bitragion-submandibular arc and face breadth) the male cases tend to cluster at the larger end of the distributions while the female cases are concentrated at the smaller end. The overlap regions for the three variables are approximately 50, 73 and 54%, respectively, indicating a more homogeneous grouping for the bitragion-submandibular arc measures.

For the sellion-menton measure the misclassified males are clustered at the smaller end of the distribution while the females are more evenly distributed over the mid and upper range

Figure 1. Bivariate Distribution Plot of Bitragion-Submandibular Arc by Sellion-Menton for Males

Sellion-Menton (millimeters)

Bitragion-Submandibular Arc (millimeters)	95–98	98–101	101–104	104–107	107–110	110–113	113–116	116–119	119–122	122–125	125–128	128–131
241–247												
247–253												
253–259												
259–265						1						
265–271			1X		3XX	1						
271–277			1X		1X	2	3	2		1		
277–283			1X	1		2	1	3	1	1		
283–289			1	1	1		4	1	2		1	
289–295			1		2	1	4	2		1	1	
295–301					3	2	2	2	1	2	1	
301–307				1	2				1	1		
307+						1	1		1			

Note: Each "X" represents one incorrectly classified case.

Figure 2. Bivariate Distribution Plot of Bitragion-Submandibular Arc by Sellion-Menton for Females

Sellion-Menton (millimeters)

Britragion-Submandibular Arc (millimeters)	< 95	95–98	98–101	101–104	104–107	107–110	110–113	113–116	116–119	119–122	122–125	125–128	128–131	> 131
< 241		1	1	1										
241–247			2											
247–253	1	3	4	2	4									
253–259		2	7	7	7	3	1	2						
259–265	1	1	5	3	4	4	2X	3X						
265–271		2	11	6	6	5	3		1					
271–277	1	2	4	4	1X	1	1		1					
277–283			3	4	7	4	1	1	1					
283–289		1	1	2		2XX	2	2						
289–295			1	1X	1	1X		1X						
295–301				1										
301–307														
> 307														

Note: Each "X" represents one incorrectly classified case.

Figure 3. Bivariate Distribution Plot of Face Breadth by Sellion-Menton for Males

Sellion-Menton (millimeters)

Face Breadth (millimeters)

Face Breadth \ Sellion-Menton	<95	95–98	98–101	101–104	104–107	107–110	110–113	113–116	116–119	119–122	122–125	125–128	128–131	>131
<117														
117–121														
121–125				1X										
125–129				2X		1	1		2					
129–133				1X		2X						1		
133–137						2X	2	3	2		1			
137–141				1	2	2	4	5	3	2	1			
141–145					1	2X	3	3	1	3	2	1		
145–149				1		1		1		1	1			
149–153						2		2	2		1	2		
>153								1						

Note: Each "X" represents one incorrectly classified case.

Figure 4. Bivariate Distribution Plot of Face Breadth by Sellion-Menton for Females

Sellion-Menton (millimeters)

Face Breadth (millimeters)	below 95	95–98	98–101	101–104	104–107	107–110	110–113	113–116	116–119	119–122	122–125	125–128	128–131	above 131
below 117		1	1	1										
117–121			2	1	1		1X							
121–125		1	5	2	5	1	1							
125–129	1	4	6	5	2		1	2						
129–133	2	2	5	5	7	4	1	1	2					
133–137		1	9	6	6	5	2	1						
137–141		3	7	11	9X	9X	5	4XX	1X					
141–145			2			1								
145–149			1					1X						
149–153						1								
above 153														

Note: Each "X" represents one incorrectly classified case.

within their distribution. All misclassified individuals fall within about 50% of the overlap region between the two distributions. For face breadth, both genders are more evenly distributed over a greater portion (80%) of the overlap region with males tending more toward the smaller end and females toward the larger end. This result goes along with the previous observation of a greater overall overlap region for this variable. The distributions of the misclassified individuals for the bitragion-submandibular arc variable are similar to face breadth distributions in that they tend to be more evenly distributed but over a lesser portion (45%) of the overlap region.

Due to the relatively small number of male cases in the sample, caution is warranted in drawing conclusions about differences between the distributions of the incorrectly classified cases across genders. Overall 6 (8.3%) of the 72 males were misclassified, (Figure 1 and Figure 3, respectively), while only 8 (5.1%) and 7 (4.4%) of the 158 females were misclassified, (Figure 2 and Figure 4, respectively).

Regression Analyses

Thus far the analyses have illustrated a statistical deviation from anthropometric proportionality across genders. Those variable groups responsible for the lack of proportionality are vertex and breadth measures. However, to provide the designer with information that can be used to improve the design and fit of face masks, more detail on the anthropometric differences between males and females must be documented. To obtain this necessary detail, regression analyses were employed.

Tables 8 through 11 contain the results of the regression analyses which estimate the relationships between two different sets of two independent variables (face breadth and sellion-menton and bitragion-submandibular arc and sellion menton) and all other variables used in the analyses. In addition to the above sets of independent measures, the dichotomous variables sex (with males coded zero and females coded one) was also used in the estimations as were the cross-product interactions between sex and each of the two independent measures. The variable sex and the two cross-product interactions were included in the analyses to provide insight as to the nature of the lack of proportionality. While significant estimated coefficients for the cross-product interactions indicate a lack of proportionality, a significant coefficient for the variable sex does not. Instead, a significant coefficient for sex only implies that the two genders differ with regard to the intercept even after controlling

Table 8. Regression Analysis of Face Mask Measures using Face Breadth and Sellion-Menton as Independent Variables

DEPENDENT VARIABLES	ADJ. R-SQUARE		FACE BREADTH		SELLION-MENTON		SEX		SEX-FACE BREADTH		SEX-SELLION-MENTON	
	R-SQ.	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
SELLION-TRAGION	0.089	8.49 *	0.255	3.38 *	0.131	1.93	D		0.007	0.85	D	
SUBNASALE-TRAGION	0.177	17.44 *	0.182	2.56 *	0.137	2.14 *	D		-0.019	-2.44 *	D	
MENTON-TRAGION	0.084	7.98 *	0.281	2.83 *	-0.137	-1.54	D		-0.033	-3.04 *	D	
GLABELLA-TRAGION	0.081	7.76 *	0.281	3.72 *	0.084	1.23	D		0.006	0.76	D	
PRONASALE-TRAGION	0.196	19.64 *	0.216	2.91 *	0.219	3.29 *	D		-0.010	-1.22	D	
STOMION-TRAGION	0.146	14.08 *	0.225	2.96 *	0.081	1.18	D		-0.020	-2.38 *	D	
ECTOCANTHUS-TRAGION	0.063	6.10 *	0.223	3.52 *	0.049	0.87	D		0.006	0.84	D	
BITRAGION-FRONTAL ARC	0.488	73.84 *	0.981	9.50 *	0.421	4.53 *	D		-0.002	-0.21	D	
BITRAGION-MENTON ARC	0.561	98.56 *	1.117	8.93 *	0.573	5.10 *	D		-0.041	-3.05 *	D	
BITRAGION-SUBMANDIBULAR ARC	0.570	102.37 *	1.356	9.82 *	0.348	2.80 *	D		-0.074	-4.99 *	D	
TRAGION-WALL	0.074	7.14 *	-0.004	-0.05	0.172	2.15 *	D		-0.017	-1.82	D	
BITRAGION BREADTH	0.650	142.94 *	0.838	18.09 *	-0.124	-2.98 *	D		-0.015	-2.98 *	D	
TRAGION-VERTEX	0.121	11.53 *	0.180	2.34 *	0.220	3.18 *	D		0.001	0.13	D	
ECTOCANTHUS-VERTEX	0.020	2.54	0.218	2.34 *	0.028	0.34	D		0.003	0.33	D	
GLABELLA-VERTEX	0.051	5.09 *	0.269	2.63 *	-0.058	-0.63	D		0.031	2.81 *	D	
SELLION-VERTEX	0.026	3.04 *	0.302	2.63 *	-0.077	-0.75	D		0.020	1.63	D	
PRONASALE-VERTEX	0.063	6.12 *	0.297	2.47 *	0.253	2.35 *	D		0.042	3.27 *	D	
SUBNASALE-VERTEX	0.081	7.74 *	0.281	2.60 *	0.290	2.99 *	D		0.038	3.23 *	D	
STOMION-VERTEX	0.149	14.37 *	0.292	2.68 *	0.434	4.43 *	D		0.024	2.03 *	D	
MENTON-VERTEX	0.395	50.90 *	0.261	2.60 *	0.824	9.15 *	D		0.022	2.06 *	D	
MINIMUM-FRONTAL BREADTH	0.485	72.85 *	0.680	10.71 *	0.116	2.03 *	D		-0.010	-1.49	D	
BIOCULAR BREADTH	0.429	58.40 *	0.414	8.08 *	0.115	2.49 *	D		-0.014	-2.62 *	D	
INTERPUPILLARY DISTANCE	0.191	19.01 *	0.257	5.18 *	0.149	3.34 *	D		0.015	2.72 *	D	
SELLION-SUBNASALE	0.546	92.89 *	0.019	0.59	0.338	11.50 *	D		-0.005	-1.32	D	
NOSE BREADTH	0.262	28.13 *	0.161	4.91 *	-0.000	-0.01	D		-0.015	-4.20 *	D	

* $p < 0.05$

D = did not enter model due to insuffient tolerance

Table 9. Regression Coefficients of the Sex - Face Breadth Interactions as a Percent of Face Breadth Coefficients

Dependent Variables	Interaction Coefficients	Face Breadth Coefficients	Percent
Subnasale-Tragion	-0.019	0.182	10.24
Menton-Tragion	-0.033	0.281	11.57
Stomion-Tragion	-0.020	0.225	8.68
Bitragion-Menton Arc	-0.041	1.117	3.69
Bitragion-Submandibular Arc	-0.074	1.356	5.48
Bitragion Breadth	-0.015	0.838	1.78
Glabella-Vertex	0.031	0.269	11.52
Pronasale-Vertex	0.042	0.297	14.23
Subnasale-Vertex	0.038	0.281	13.40
Stomion-Vertex	0.024	0.292	8.14
Menton-Vertex	0.022	0.261	8.53
Biocular Breadth	-0.014	0.414	3.49
Interpupillary Distance	0.015	0.257	5.66
Nose Breadth	-0.015	0.161	9.21

Table 10. Regression Analysis of Face Mask Measures using Bitragion-Submandibular Arc and Sellion-Menton as Independent Variables

DEPENDENT VARIABLES	ADJ. R-SQUARE		BITRAG-SUBMAN ARC		FACE BREADTH		SEX		SEX-BITRAG-SUBMAN ARC		SEX-SELLION-MENTON	
	R-SQ.	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
SELLION-TRAGION	0.126	12.01 *	0.140	4.63 *	0.091	1.41	0		0		0.019	1.88
SUBNASALE-TRAGION	0.195	19.43 *	0.094	3.27 *	0.126	2.05 *	0		0		-0.015	-1.57
MENTON-TRAGION	0.119	11.26 *	0.158	3.96 *	-0.163	-1.92	0		0		-0.027	-2.00
GLABELLA-TRAGION	0.124	11.77 *	0.152	5.04 *	0.042	0.64	0		0		0.019	1.87
PRONASALE-TRAGION	0.215	21.95 *	0.110	3.66 *	0.199	3.12 *	0		0		-0.004	-0.38
STOMION-TRAGION	0.160	15.59 *	0.105	3.39 *	0.073	1.11	0		0		-0.016	-1.56
ECTOCANTHUS-TRAGION	0.083	7.95 *	0.108	4.23 *	0.024	0.43	0		0		0.014	1.64
BITRAGION-FRONTAL ARC	0.384	48.52 *	0.271	5.84 *	0.476	4.81 *	0		0		0.003	0.21
BITRAGION-MENTON ARC	0.697	176.21 *	0.611	14.34 *	0.428	4.71 *	0		0		-0.005	-0.34
TRAGION-WALL	0.076	7.25 *	0.026	0.71	0.163	2.11 *	0		0		-0.017	-1.38
BITRAGION BREADTH	0.355	43.01 *	0.209	8.12 *	-0.049	-0.88	0		0		-0.014	-1.66
TRAGION-VERTEX	0.106	10.02 *	0.037	1.16	0.241	3.55 *	0		0		0.001	0.10
ECTOCANTHUS-VERTEX	0.059	5.79 *	0.146	3.89 *	-0.024	-0.31	0		0		0.016	1.29
GLABELLA-VERTEX	0.081	7.72 *	0.162	3.93 *	-0.125	-1.42	0		0		0.049	3.60 *
SELLION-VERTEX	0.085	8.09 *	0.216	4.73 *	-0.169	-1.73	0		0		0.043	2.82 *
PRONASALE-VERTEX	0.116	11.01 *	0.220	4.61 *	0.144	1.42	0		0		0.069	4.35 *
SUBNASALE-VERTEX	0.124	11.85 *	0.191	4.42 *	0.200	2.17 *	0		0		0.060	4.20 *
STOMION-VERTEX	0.212	21.52 *	0.221	5.14 *	0.334	3.65 *	0		0		0.048	3.35 *
MENTON-VERTEX	0.424	57.14 *	0.174	4.34 *	0.753	8.81 *	0		0		0.041	3.10 *
MINIMUM-FRONTAL BREADTH	0.304	34.27 *	0.141	4.66 *	0.194	3.01 *	0		0		-0.014	-1.39
FACE BREADTH	0.461	66.26 *	0.213	9.32 *	0.104	2.15 *	0		0		-0.002	-0.22
BIOCULAR BREADTH	0.340	40.33 *	0.103	4.58 *	0.152	3.15 *	0		0		-0.017	-2.20 *
INTERPUPILLARY DISTANCE	0.123	11.66 *	0.062	2.92 *	0.161	3.57 *	0		0		0.017	2.44 *
SELLION-SUBNASALE	0.547	93.25 *	0.009	0.66	0.337	11.84 *	0		0		-0.005	-1.19
NOSE BREADTH	0.254	26.93 *	0.059	4.34 *	0.008	0.28	0		0		-0.014	-3.16 *

* $p < 0.05$

0 = did not enter model due to insuffient tolerance

Table 11. Regression Coefficients of the Sex - Sellion-Menton Interactions as a Percent of Sellion-Menton Coefficients

Dependent Variables	Interaction Coefficients	Sellion-Menton Coefficients	Ratio (Percent)
Glabella-Vertex	0.049	-0.125	39.45
Sellion-Vertex	0.043	-0.169	25.44
Pronasale-Vertex	0.069	0.144	48.00
Subnasale-Vertex	0.060	0.200	30.17
Stomion-Vertex	0.048	0.334	14.34
Menton-Vertex	0.041	0.753	5.49
Biocular Breadth	-0.017	0.152	10.87
Interpupillary Distance	0.017	0.161	10.68
Nose Breadth	-0.014	0.008	174.10

for the two independent measures. A complete listing of all male and female regression equations for all models is given in Tables 13 and 14, Appendix B.

An examination of Table 8 demonstrates a very limited degree of association between face breadth and sellion-menton and the other face dimensions. Even though 24 of the 25 estimated models are statistically significant, only four (bitragion breadth, bitragion-submandibular arc, bitragion-menton arc and sellion-subnasal) have adjusted R^2 values greater than 0.500. The remaining 20 significant models have a mean adjusted R^2 value of only 0.203. For 23 of the 25 models face breadth is statistically significant while sellion-menton is significant for 16 of the models. Neither sex nor the interaction of sex and sellion-menton attained sufficient tolerance levels to enter the models. However, the sex-face breadth interaction is significant for 14 models. The pattern of the interactions is consistent with the results of the discriminant analyses. All major groups of variables (tragion, arc, vertex and breadth measures) are represented in the equations where the sex-face breadth interactions are significant. In addition, the signs of the estimated coefficients are as expected. That is, all coefficients are negative for tragion, breadth, and arc measures indicating smaller measures for females after controlling for sellion-menton and face breadth. Conversely, the coefficients for the vertex measures are positive indicating larger measures for these variables once the two independent measures are controlled.

To assess the potential impact that the observed lack of proportionality has on the design and fit of facemasks, each significant interaction coefficient was compared to the face breadth coefficient. The results are contained in Table 9. It appears that the vertex measures are most affected by the interactions followed by the tragion measures. The arc measures and the breadth measures appear least affected.

In summary, these results indicate a lack of proportionality across genders with regard to the structure of the head and face. In general, one could conclude that once face length (sellion-menton) and face breadth are controlled, women's faces are likely to exhibit less depth (tragion measures), breadth and arc (a function of the first two dimensions). Conversely, the upper parts of women's faces (vertex measures) are likely to be longer than men's. In addition, it is the vertex measures which are proportionately most affected.

Table 10 contains the estimated regression models in which bitragion-submandibular arc and sellion-menton distance were used as the independent variables. A comparison of the results from this analysis with those presented in Table 8 reveals that the substitution of submandibular arc length for face breadth results in models which provide slightly better predictions for most of the dependent measures, with the exceptions being the breadth measures. Even though all 25 models are statistically significant, only two (bitragion-menton arc and sellion-subnasale) have adjusted R^2 values greater than 0.500. The remaining 23 models have a slightly greater mean adjusted R^2 value of 0.216. Sellion-menton is significant for only 14 models compared with 16 in the previous model (Table 8) while bitragion-submandibular arc is not significant for three of the models. Similar to the previous results, the sex variable fails to meet the tolerance criteria for inclusion in the model. The significant difference between the models estimated in Table 8 and those estimated in Table 10 is that while the sex-sellion-menton interaction failed to enter any of the equations in Table 8, this interaction term is significant for 9 models in this analysis. Similar to the previous model, the sex-bitragion-submandibular arc interaction never achieved sufficient tolerance to enter any of the equations.

The distribution of the significant interaction term is somewhat more restricted in the equations in Table 10. While significant interaction effects were found within all four head and face dimensions in the previous model, in the current models the interactions are limited to the vertex and breadth dimensions. However, the relative impact of the sex-sellion-menton interactions is much greater compared to the sex-face breadth interactions (Table 11). For example, five of the nine interaction terms are greater than 25% of the sellion-menton coefficients and the coefficient for nose breadth is 1.74 times greater than that of the sellion-menton coefficient. The signs of the interaction coefficients are consistent with those observed in Table 8. That is, once bitragion-submandibular arc and sellion-menton are controlled, females have larger vertex distances and smaller facial breadth measurements. Overall, the regression analyses indicate the presence of a considerable lack of cross-gender proportionality within the anthropometric structure of the head and face. For those models where sellion-menton and face breadth were used as independent variables, the cross-gender interaction occurred with face breadth. In addition, its effect is distributed across all dimensions of the head and facial structure, although its impact is greatest on vertex and tragion distances. For models where bitragion-submandibular arc and sellion-menton were used as the independent variables, the sex interaction involves the sellion-menton distance. For this set of equations, the interactions are restricted to vertex distances and facial breadths. However, the impact is much greater than for the other set of equations.

Table 12 contains a summary of the differences in the output from the male and female specific regression models. A more detailed listing of the differences is given in Tables 15 and 16, Appendix C. Two sets of gender specific models were used. One set relied on sellion-menton distance and face breadth as the independent variables, while the other set used sellion-menton distance and bitragion-submandibular arc. Input data for these independent variables were obtained by selecting values common to both the male and female sub-samples. After estimating values for the dependent variables, corresponding female estimates were subtracted from the male estimates. Therefore negative values indicate larger predicted female dimensions.

For the sellion-menton distance - face breadth models, the greatest disparities between genders occur within the estimates of bitragion-submandibur arc, with a maximum difference of 16mm and a minimum difference of 5mm. The smallest differences were found for the estimates of sellion-tragion distance (0.28,-0.12mm). The estimated to-vertex measures are consistently smaller for the men, with pronasale-vertex having the greatest differences (-5.05, -6.33mm) within this group. The opposite pattern was observed for the to-tragion measures, with the exception of the ectocanthus-tragion distance. Overall, the estimated breadth measures are greater for the men, with the exception of interpupillary distance.

For the models estimated from bitragion-submandibular arc and sellion-menton distance, the differences in estimated values for the other arc measures were significantly decreased. The estimated to-vertex measures remain greater for the women. However, the differences are larger than those estimated in the previous models. In addition, the pattern of differences within the to-tragion measures is not as consistent as was found for the sellion-menton-face breadth model. For example, three of the seven estimated maximum to-tragion measures and four of the seven minimum values are greater for females compared to none and three values, respectively, for the previous models.

In summarizing the results from Table 12, it appears that estimating male and female head and face measurements from a single model produces inaccurate results, at least within those regions where the distributions for the males and females overlap. In addition, there appears to be a pattern to the inaccuracies. In general, male models under-estimate to-vertex and interpupillary distances of females, while overestimating most other measures.

Table 12. Maximum and Minimum Differences Between Male and Female Measurements Estimated from Separate Regression Models

Dependent Variable	Independent Variables: Sellion-Menton & Face Breadth		Independent Variables: Sellion-Menton Britragion-Submandibular Arc	
	Maximum	Minimum	Maximum	Minimum
Sellion-Tragion	0.28	-0.12	-1.40	-3.24
Subnasale-Tragion	1.88	1.74	2.05	1.19
Menton-Tragion	3.58	-0.06	4.86	3.14
Glabella-Tragion	1.70	0.81	-1.20	-3.51
Pronasale-Tragion	1.70	0.83	1.31	-0.90
Stomion-Tragion	2.02	0.97	2.16	1.32
Ectocanthus-Tragion	0.29	-1.61	-0.09	-3.79
Bitragion-Frontal Arc	0.94	-0.42	0.48	-1.80
Bitragion-Menton Arc	11.50	0.16	1.66	-1.30
Bitragion-Submandibular Arc	16.02	5.02	-----	-----
Tragion-Wall	3.17	1.71	4.69	0.08
Bitragion Breadth	3.11	1.14	3.24	-0.43
Tragion-Vertex	0.43	-0.70	1.86	-1.44
Ectocanthus-Vertex	-0.06	-0.92	-0.44	-2.99
Glabella-Vertex	-3.80	-4.67	-3.68	-7.08
Sellion-Vertex	-2.39	-3.02	-3.70	-5.66
Pronasale-Vertex	-5.05	-6.33	-6.57	-8.82
Subnasale-Vertex	-4.37	-5.78	-6.08	-7.59
Stomion-Vertex	-2.55	-3.78	-4.39	-6.13
Menton-Vertex	-2.45	-3.50	-2.95	-5.84
Sellion Menton	-----	-----	-----	-----
Minimum-Frontal Breadth	3.56	-1.25	2.67	-0.32
Face Breadth	-----	-----	1.90	-2.43
Biocular Breadth	2.81	0.94	2.87	0.47
Interpupillary Distance	-1.41	-2.66	-1.43	-2.86
Sellion-Subnasale	1.12	0.06	1.66	-1.05
Nose Breadth	2.65	1.43	2.14	1.30

Note: All measures are in millimeters; negative values indicate larger female dimensions.

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APPENDIX A

VARIABLE DESCRIPTIONS

The variable descriptions and figures included in this Appendix are modified from figures shown in Tebbetts, Churchill & McConville (1980).

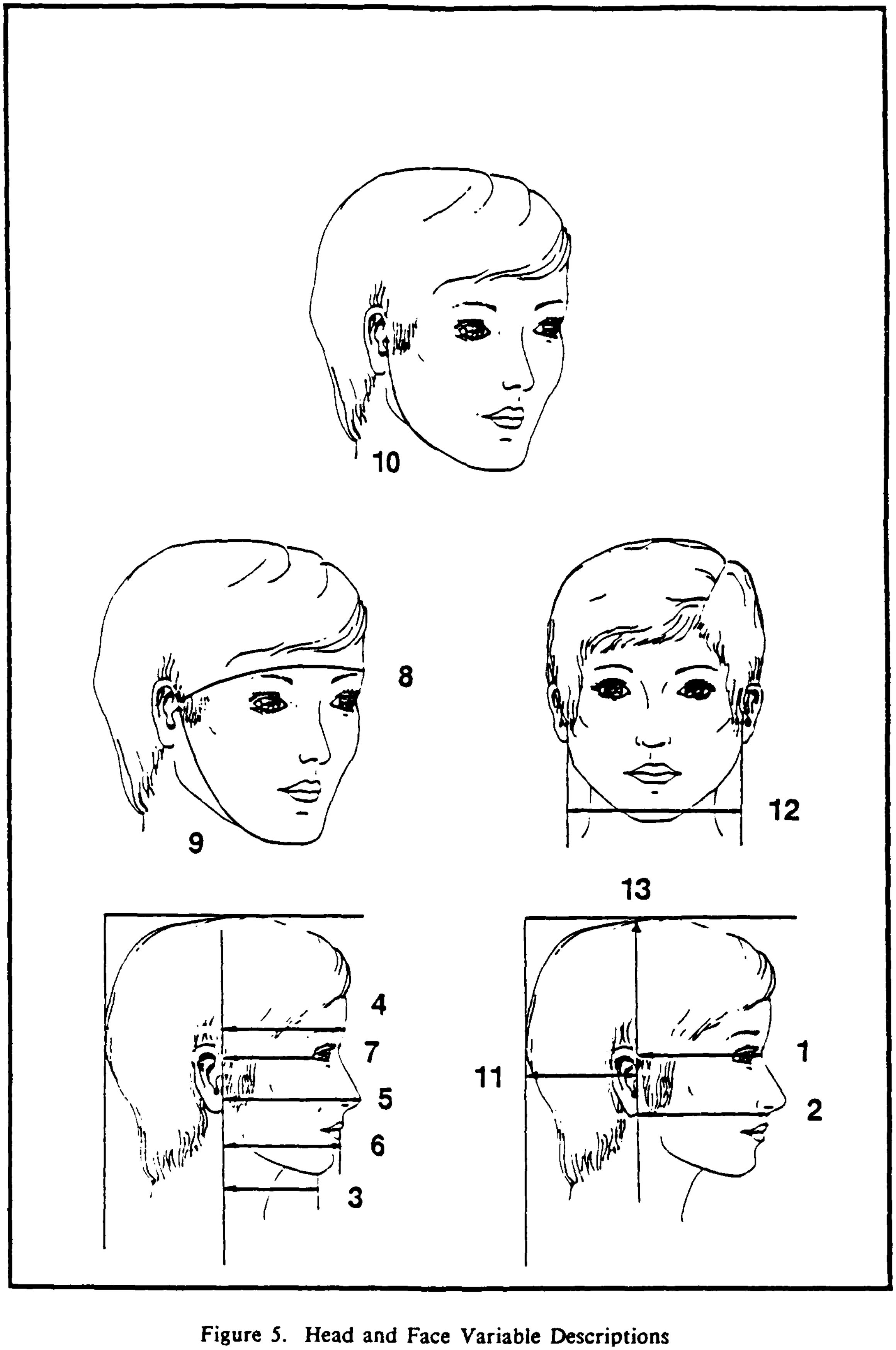

Figure 5. Head and Face Variable Descriptions

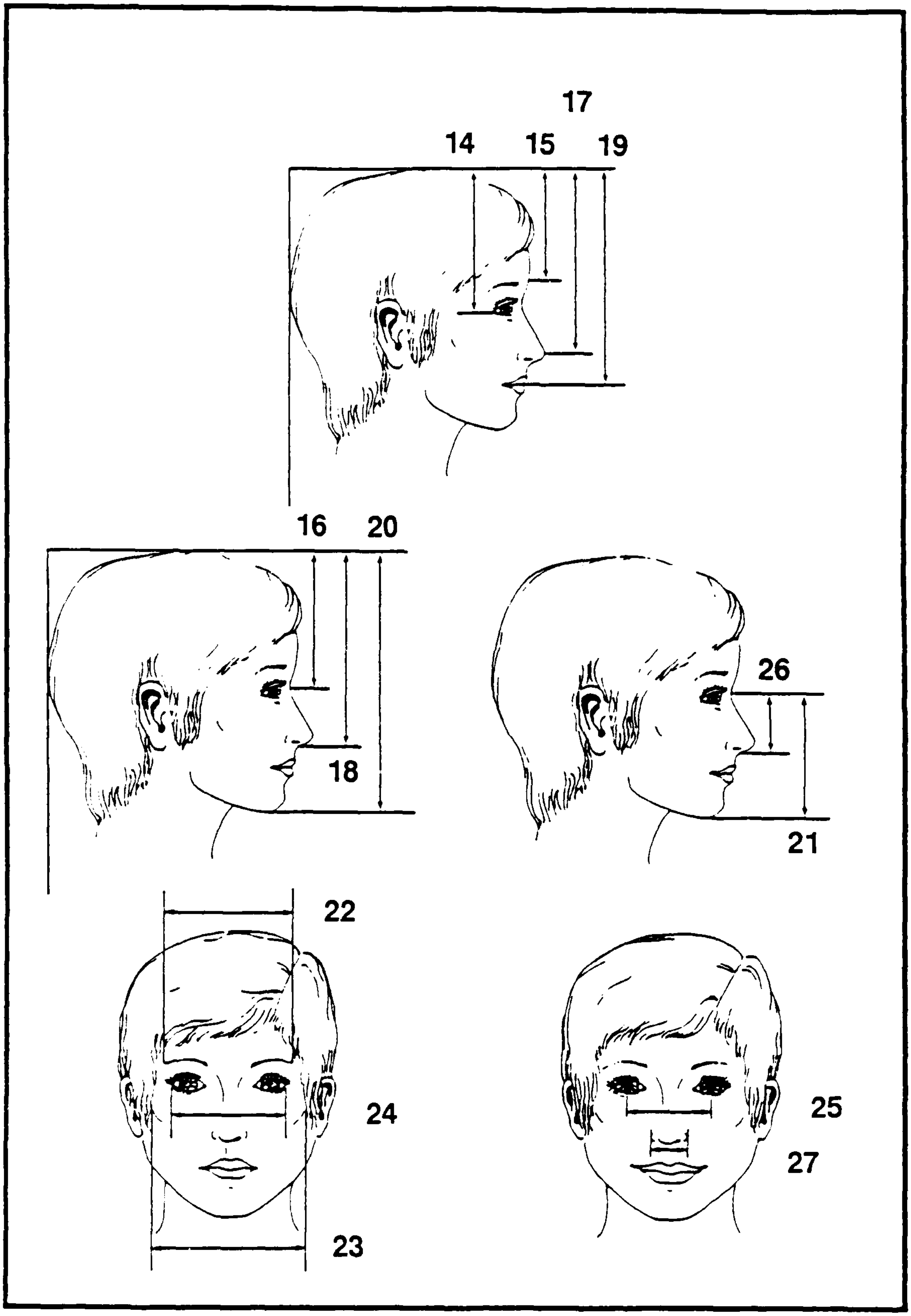

Figure 5 (Continued). Head and Face Variable Descriptions

1. SELLION-TRAGION: horizontal distance from the deepest point in the nasal root depression to the cartilaginous notch just forward of the ear hole.

2. SUBNASALE-TRAGION: horizontal distance from the base of the nasal septum to the cartilaginous notch just forward of the ear hole.

3. MENTON-TRAGION: horizontal distance from the tip of the chin to the cartilaginous notch just forward of the ear hole.

4. GLABELLA-TRAGION: horizontal distance from the most anterior point between the brow ridges to the cartilaginous notch just forward of the ear hole.

5. PRONASALE-TRAGION: horizonal distance from the base of the nasal septum to the cartilaginous notch just forward of the ear hole.

6. STOMION-TRAGION: horizontal distance from the point of contact of the lips in the midsagittal plane to the cartilaginous notch just forward of the ear hole.

7. ECTOCANTHUS-TRAGION: horizontal distance from the outer corner of the eye to the cartilaginous notch just forward of the ear hole.

8. BITRAGION-FRONTAL ARC: distance from right tragion (the notch just forward of the ear hole) to left tragion measured across the forehead.

9. BITRAGION-MENTON ARC: distance from right tragion (the notch just forward of the ear hole) to left tragion measured with the tape passing under the tip of the chin.

10. BITRAGION-SUBMANDIBULAR ARC: distance from right tragion (the notch just forward of the ear hole) to left tragion measured with the tape passing under the gonial angles of the jaw and over the jaw-neck juncture.

11. TRAGION TO WALL: horizontal distance from the cartilaginous notch just forward of the ear hole to the coronal plan tangent to the back of the head.

12. BITRAGION BREADTH: breadth of the head between the notches just forward of the ear holes.

13. TRAGION-VERTEX: vertical distance from the cartilaginous notch just forward of the ear hole to the level of the top of the head.

14. ECTOCANTHUS TO VERTEX: vertical distance from the outer corner of the eye to the level of the top of the head.

15. GLABAELLA TO VERTEX: vertical distance from the most anterior point between the brow ridges to top of the head.

16. SELLION TO VERTEX: vertical distance from the deepest point in the nasal root depression to top of the head.

17. PRONASALE TO VERTEX: vertical distance from tip of the nose to top of the head.

18. SUBNASALE TO VERTEX: vertical distance from the base of the nasal septum to the level of the top of the head.

19. STOMION TO VERTEX: vertical distance from the point of contact of the lips in the midsagittal plane to top of the head.

20. MENTON TO VERTEX: vertical distance from tip of the chin to the level of the top of the head.

21. SELLION-MENTON: vertical distance from the deepest point in the nasal root depression to tip of the chin.

22. MINIMUM FRONTAL BREADTH: breadth of the forehead between the greatest indentations of the temporal crests above the brow ridges.

23. FACE BREADTH: breadth of the face across the zygomatic arches.

24. BIOCULAR BREADTH: distance between the outer corners of the eyes.

25. INTERPUPILLARY DISTANCE: distance between the centers of the pupils.

26. SELLION-SUBNASALE: vertical distance from the lowest point in the nasal root depression to the base of the nasal septum.

27. NOSE BREADTH: maximum breadth of the nose.

APPENDIX B

MALE AND FEMALE REGRESSION EQUATIONS FOR ALL MODELS

Table 13. Regression Analysis of Face Mask Measures Using Face Breadth and Sellion-Menton Distance as Independent Variables

DEPENDENT VARIABLES	ADJ. R-SQUARED		FACE BREADTH		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
SELLION-TRAGION DISTANCE								
male	0.052	2.96 *	0.254	1.88	0.093	0.87	49.533	2.53 *
female	0.074	7.27 *	0.262	2.81 *	0.159	1.78	39.891	2.96 *
SUBNASAL-TRAGION DISTANCE								
male	0.039	2.42	0.185	1.43	0.116	1.14	66.227	3.68 *
female	0.043	4.55 *	0.162	1.86	0.152	1.83	62.757	4.99 *
MENTON-TRAGION DISTANCE								
male	-0.011	0.60	0.056	0.29	-0.165	-1.09	85.391	4.22 *
female	0.044	4.64 *	0.355	3.04 *	-0.109	-0.98 *	58.945	3.50 *
GLABELLA-TRAGION DISTANCE								
male	0.051	2.90	0.272	2.03 *	0.062	0.59	49.804	2.67 *
female	0.068	6.75 *	0.292	3.11 *	0.099	1.11	43.785	3.23 *
PRONASAL-TRAGION DISTANCE								
male	0.102	5.04 *	0.181	1.41	0.228	2.25 *	68.266	3.82 *
female	0.079	7.74 *	0.222	2.39 *	0.214	2.41 *	63.030	4.70 *
STOMION-TRAGION DISTANCE								
male	0.006	1.23	0.185	1.19	0.073	0.59	69.752	3.22 *
female	0.047	4.87 *	0.224	2.56 *	0.088	1.06	60.064	4.76 *
ECTOCANTHUS-TRAGION DISTANCE								
male	0.003	1.12	0.132	1.16	0.047	0.53	48.261	3.05 *
female	0.076	7.46 *	0.271	3.48 *	0.054	0.73	29.429	2.62 *

Table 13. Continued page 2 of 4

DEPENDENT VARIABLES	ADJ. R-SQUARED		FACE BREADTH		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
BITRAGION FRONTAL ARC								
male	0.411	25.78 *	0.963	5.05 *	0.485	3.24 *	105.436	3.98 *
female	0.357	44.64 *	0.987	7.83 *	0.375	3.12 *	114.133	6.27 *
BITRAGION-MENTON ARC								
male	0.289	15.41 *	0.561	2.46 *	0.707	3.94 *	149.471	4.72 *
female	0.422	58.22 *	1.338	8.98 *	0.496	3.50 *	62.373	2.90 *
BITRAGION-SUBMANDELA ARC								
male	0.143	6.91 *	0.728	2.75 *	0.313	1.50	148.965	4.05 *
female	0.443	63.48 *	1.578	9.94 *	0.396	2.62 *	14.352	0.63
TRAGION-WALL DISTANCE								
male	-0.019	0.32	-0.029	-0.18	0.098	0.80	94.740	4.39 *
female	0.018	2.42	-0.010	-0.09	0.226	2.15 *	75.365	4.72 *
BITRAGION BREADTH								
male	0.499	36.30 *	0.811	8.52 *	-0.224	-2.99 *	49.841	3.77 *
female	0.629	133.95 *	0.836	16.06 *	-0.050	-1.02	24.903	3.31 *
TRAGION-VERTEX DISTANCE								
male	0.079	4.06 *	0.213	1.58	0.186	1.75	84.101	4.47 *
female	0.067	6.61 *	0.165	1.72 *	0.243	2.66 *	84.386	6.09 *
ECTOCANTHUS-VERTEX DISTANCE								
male	0.015	1.53	0.247	1.49	0.051	0.40	71.971	3.13 *
female	0.010	1.77	0.208	1.79	0.011	0.10	82.253	4.91 *

Table 13. Continued page 3 of 4

DEPENDENT VARIABLES	ADJ. R-SQUARED		FACE BREADTH		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
GLABELLA-VERTEX DISTANCE								
male	0.017	1.63	0.319	1.78	-0.037	-0.27	41.765	1.68
female	0.017	2.33	0.276	2.16 *	-0.075	-0.62	55.978	3.03 4
SELLION-VERTEX DISTANCE								
male	-0.003	0.91	0.302	1.34	-0.102	-0.57	68.391	2.18 *
female	0.023	2.82	0.322	2.37 *	-0.060	-0.46	63.789	3.26 *
PRONASAL-VERTEX DISTANCE								
male	0.041	2.51	0.265	1.14	0.267	1.46	66.319	2.06 *
female	0.063	6.22 *	0.354	2.48 *	0.245	1.80	62.468	3.03 *
SUBNASAL-VERTEX DISTANCE								
male	0.083	4.20 *	0.250	1.28	0.315	2.06 *	76.097	2.81 *
female	0.074	7.27 *	0.333	2.50 *	0.272	2.15 *	74.901	3.90 *
STOMION-VERTEX DISTANCE								
male	0.117	5.72 *	0.261	1.28	0.411	2.56 *	86.392	3.05 *
female	0.130	12.69 *	0.330	2.51 *	0.451	3.59 *	75.591	3.97 *
MENTON-VERTEX DISTANCE								
male	0.357	20.73 *	0.289	1.59	0.774	5.41 *	84.544	3.35 *
female	0.306	35.57 *	0.270	2.19 *	0.860	7.36 *	80.462	4.52 *
MINIMUM FRONTAL BREADTH								
male	0.385	23.18 *	0.835	5.56 *	0.231	1.96	-30.249	-1.45
female	0.391	51.42 *	0.597	9.68 *	0.027	0.47	23.512	2.64 *

Table 13. Continued page 4 of 4

DEPENDENT VARIABLES	ADJ. R-SQUARED		FACE BREADTH		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
BIOCULAR BREADTH								
male	0.353	20.40 *	0.391	4.36 *	0.215	3.04 *	21.507	1.73
female	0.226	23.89 *	0.410	6.47 *	0.043	0.71	36.327	3.97 *
INTERPUPILLARY DISTANCE								
male	0.259	13.38 *	0.279	3.08 *	0.212	2.97	-4.607	-0.37
female	0.140	13.76 *	0.261	4.32 *	0.103	1.79	11.998	1.38
SELLION-SUBNASAL DISTANCE								
male	0.559	46.09 *	0.003	0.06	0.389	9.09 *	4.499	0.60
female	0.287	32.55 *	0.022	0.54	0.301	7.65 *	11.187	1.88
NOSE BREADTH								
male	0.055	3.07	0.177	2.48 *	-0.047	-0.83	15.980	1.61
female	0.099	9.59 *	0.139	3.89 *	0.033	0.96	10.248	1.99 *

* $p < 0.05$
N (males) = 72
N (females) = 158

Table 14. Regression Analysis of Face Mask Measures Using Bitragion-Submandibular Arc and Sellion-Menton as Independent Variable

DEPENDENT VARIABLES	ADJ. R-SQUARED		BRITAGION-SUBMANDIBULAR		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
SELLION-TRAGION DISTANCE								
male	0.041	2.50	0.095	1.62	0.109	10.33	53.262	2.98 *
female	0.137	13.43 *	0.158	4.44 *	0.099	1.13	38.919	3.55 *
SUBNASAL-TRAGION DISTANCE								
male	0.035	2.29	0.075	1.34	0.125	1.24	69.179	4.06 *
female	0.075	7.40 *	0.101	2.99 *	0.112	1.34	61.532	5.90 *
MENTON-TRAGION DISTANCE								
male	0.019	1.70	0.123	1.50	-0.212	-1.50	88.346	3.55 *
female	0.070	6.87 *	0.168	3.70 *	-0.154	-1.38	65.930	4.71 *
GLABELLA-TRAGION DISTANCE								
male	0.039	2.43	0.104	0.08 *	0.079	0.75	55.501	3.13 *
female	0.141	13.86 *	0.173	4.85 *	0.036	0.41	43.290	3.95 *
PRONASAL-TRAGION DISTANCE								
male	0.098	4.84 *	0.071	1.27	0.238	2.38 *	71.683	4.23 *
female	0.116	11.27 *	0.127	3.52 *	0.169	1.91	63.580	5.74 *
STOMION-TRAGION DISTANCE								
male	0.011	1.38	0.088	1.31	0.076	0.63	69.806	3.42 *
female	0.070	6.93 *	0.111	3.26 *	0.056	0.67	63.569	6.05 *
ECTOCANTHUS-TRAGION DISTANCE								
male	-0.012	0.59	0.027	0.55	0.067	0.75	56.378	3.73 *
female	0.130	12.72 *	0.141	4.67 *	0.010	0.13	32.444	3.53 *

Table 14. Continued page 2 of 4

DEPENDENT VARIABLES	ADJ. R-SQUARED		BRITAGION-SUBMANDIBULAR		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
BITRAGION FRONTAL ARC								
male	0.282	14.97 *	0.266	2.93 *	0.594	3.64 *	149.014	5.39 *
female	0.234	24.93 *	0.280	5.14 *	0.396	2.96 *	167.831	10.03 *
BITRAGION-MENTON ARC								
male	0.601	54.39 *	0.593	8.04 *	0.534	4.18 *	75.069	3.34 *
female	0.540	93.28 *	0.624	11.90 *	0.334	2.59 *	90.676	5.62 *
FACE BREADTH								
male	0.166	8.06 *	0.136	2.75 *	0.183	2.06 *	77.251	5.14 *
female	0.421	58.10 *	0.247	9.94 *	0.050	0.82	61.048	8.00 *
TRAGION-WALL DISTANCE								
male	-0.010	1.35	0.095	1.44	0.043	0.37	70.003	3.48 *
female	0.018	2.43	-0.007	-0.16	0.229	2.14 *	75.593	5.62 *
BITRAGION BREADTH								
male	0.037	2.38	0.124	2.17 *	-0.083	-0.81	109.383	6.31 *
female	0.337	40.84 *	0.240	8.72 *	-0.035	-0.52	69.811	8.25 *
TRAGION-VERTEX DISTANCE								
male	0.085	4.31 *	0.100	1.72	0.190	1.82	84.359	4.76 *
female	0.049	5.07 *	0.010	0.26	0.275	2.93 *	100.025	8.49 *
ECTOCANTHUS-VERTEX DISTANCE								
male	0.096	4.79 *	0.201	2.94 *	0.013	0.11	52.823	2.54 *
female	0.038	4.08 *	0.127	2.80 *	-0.037	-0.34	81.314	5.84 *

Table 14. Continued page 3 of 4

DEPENDENT VARIABLES	ADJ. R-SQUARED		BRITAGION-SUBMANDIBULAR		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
GLABELLA-VERTEX DISTANCE								
male	0.115	5.62 *	0.245	3.34 *	-0.079	-0.60	20.448	0.92
female	0.031	3.54 *	0.133	2.66 *	-0.112	-0.91	60.968	3.95 *
SELLION-VERTEX DISTANCE								
male	0.077	3.97 *	0.263	2.81 *	-0.156	-0.93	41.288	1.45
female	0.038	7.26 *	0.199	3.81 *	-0.137	-1.06	61.809	3.85 *
PRONASAL-VERTEX DISTANCE								
male	0.128	6.20 *	0.275	2.89 *	0.197	1.15	32.281	1.11
female	0.103	9.99 *	0.202	3.66 *	0.173	1.28	63.260	3.72 *
SUBNASAL-VERTEX DISTANCE								
male	0.150	7.26 *	0.218	2.69 *	0.270	1.86	53.552	2.17 *
female	0.110	10.71 *	0.184	3.58 *	0.209	1.65	76.647	4.84 *
STOMION-VERTEX DISTANCE								
male	0.209	10.37 *	0.261	3.13 *	0.347	2.32 *	55.244	2.18 *
female	0.182	18.49 *	0.206	4.08 *	0.371	2.99 *	73.174	4.71 *
MENTON-VERTEX DISTANCE								
male	0.414	26.06 *	0.230	3.07 *	0.732	5.44 *	63.404	2.78 *
female	0.327	39.23 *	0.151	3.16 *	0.807	6.85 *	81.558	5.53 *
MINIMUM FRONTAL BREADTH								
male	0.156	7.54 *	0.148	1.96 *	0.366	2.69 *	26.201	1.13
female	0.167	16.73 *	0.148	5.18 *	0.057	0.81	59.908	6.83 *

Table 14. Continued page 4 of 4

DEPENDENT VARIABLES	ADJ. R-SQUARED		BRITAGION-SUBMANDIBULAR		SELLION-MENTON DIST.		CONSTANT	
	R-SQ	F-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio	Coeff.	T-Ratio
BIOCULAR BREADTH								
male	0.270	14.11 *	0.123	2.99 *	0.251	3.40 *	35.802	2.86 *
female	0.098	9.56 *	0.101	3.75 *	0.063	0.95	61.316	7.37 *
INTERPUPILLARY DISTANCE								
male	0.184	9.00 *	0.062	1.51	0.251	3.40 *	11.415	0.91
female	0.080	7.78 *	0.067	2.69 *	0.114	1.88	27.516	3.62 *
SELLION-SUBNASAL DISTANCE								
male	0.570	47.97 *	-0.030	-1.27	0.404	9.69 *	11.586	1.64
female	0.298	34.32 *	0.027	1.67	0.285	7.17 *	8.637	1.73
NOSE BREADTH								
male	0.031	2.12	0.064	2.06 *	-0.034	-0.61	20.478	2.15 *
female	0.097	9.42 *	0.054	3.85 *	0.024	0.69	15.083	3.47 *

* $p < 0.05$
N (males) = 72
N (females) = 158

APPENDIX C

ESTIMATED DIFFERENCES BETWEEN MALES AND FEMALES FOR ALL INDEPENDENT VARIABLES, FOR ALL MODELS

NOTE: All Dimensions in millimeters; negative values indicate larger female dimensions

Table 15. Estimated Male minus Female Computed Values with Sellion-Menton and Face Breadth as Dependent Variables

		Sellion-Menton			
Sellion-Tragion		107.20	110.40	113.60	116.80
	129.00	0.28	0.15	0.03	-0.10
Face Breadth	133.00	0.27	0.15	0.02	-0.11
	137.00	0.27	0.14	0.01	-0.11
	141.00	0.26	0.13	0.01	-0.12

		Sellion-Menton			
Subnasale-Tragion		107.20	110.40	113.60	116.80
	129.00	1.88	1.84	1.81	1.77
Face Breadth	133.00	1.87	1.83	1.80	1.76
	137.00	1.86	1.82	1.79	1.75
	141.00	1.85	1.81	1.78	1.74

		Sellion-Menton			
Menton-Tragion		107.20	110.40	113.60	116.80
	129.00	3.58	3.41	3.24	3.07
Face Breadth	133.00	2.53	2.37	2.20	2.03
	137.00	1.49	1.32	1.16	0.99
	141.00	0.45	0.28	0.11	-0.06

		Sellion-Menton			
Glabella-Tragion		107.20	110.40	113.60	116.80
	129.00	1.70	1.49	1.27	1.06
Face Breadth	133.00	1.62	1.40	1.19	0.98
	137.00	1.54	1.32	1.11	0.90
	141.00	1.45	1.24	1.03	0.81

		Sellion-Menton			
Pronasale-Tragion		107.20	110.40	113.60	116.80
	129.00	1.44	1.53	1.62	1.70
Face Breadth	133.00	1.24	1.33	1.41	1.50
	137.00	1.04	1.12	1.21	1.30
	141.00	0.83	0.92	1.01	1.10

Table 15. Continued page 2 of 5

Stomion-Tragion		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	1.96	1.98	2.00	2.02
Face Breadth	133.00	1.63	1.65	1.67	1.69
	137.00	1.30	1.32	1.34	1.36
	141.00	0.97	0.99	1.01	1.03

Ectocanthus-Tragion		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	0.29	0.19	0.09	-0.01
Face Breadth	133.00	-0.24	-0.34	-0.44	-0.54
	137.00	-0.78	-0.88	-0.98	-1.08
	141.00	-1.32	-1.42	-1.52	-1.61

Bitragion-Frontal Arc		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	-0.12	0.23	0.59	0.94
Face Breadth	133.00	-0.22	0.13	0.49	0.84
	137.00	-0.32	0.03	0.39	0.74
	141.00	-0.42	-0.06	0.29	0.64

Bitragion-Menton Arc		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	9.48	10.15	10.83	11.50
Face Breadth	133.00	6.37	7.04	7.72	8.39
	137.00	3.26	3.94	4.61	5.29
	141.00	0.15	0.83	1.50	2.18

Bitragion-Submandibular Arc		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	16.02	15.76	15.49	15.23
Face Breadth	133.00	12.62	12.35	12.09	11.82
	137.00	9.22	8.95	8.69	8.42
	141.00	5.82	5.55	5.29	5.02

Table 15. Continued page 3 of 5

Tragion-Wall		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	3.17	2.76	2.35	1.94
Face Breadth	133.00	3.10	2.68	2.27	1.86
	137.00	3.02	2.61	2.20	1.79
	141.00	2.95	2.54	2.12	1.71

Bitragion Breadth		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	3.11	2.55	1.99	1.44
Face Breadth	133.00	3.01	2.45	1.90	1.34
	137.00	2.91	2.35	1.80	1.24
	141.00	2.81	2.25	1.70	1.14

Tragion-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	-0.15	-0.33	-0.52	-0.70
Face Breadth	133.00	0.04	-0.14	-0.32	-0.51
	137.00	0.23	0.05	-0.13	-0.31
	141.00	0.43	0.24	0.06	-0.12

Ectocanthus-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	-0.92	-0.79	-0.65	-0.52
Face Breadth	133.00	-0.76	-0.63	-0.50	-0.37
	137.00	-0.61	-0.48	-0.35	-0.21
	141.00	-0.45	-0.32	-0.19	-0.06

Glabella-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
	129.00	-4.67	-4.55	-4.43	-4.31
Face Breadth	133.00	-4.50	-4.38	-4.26	-4.14
	137.00	-4.33	-4.21	-4.09	-3.97
	141.00	-4.16	-4.04	-3.92	-3.80

Table 15. Continued page 4 of 5

Sellion-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-2.39	-2.67	-2.66	-2.79
	133.00	-2.47	-2.60	-2.74	-2.87
	137.00	-2.55	-2.68	-2.81	-2.95
	141.00	-2.62	-2.76	-2.89	-3.02

Pronasale-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-5.26	-5.19	-5.12	-5.05
	133.00	-5.62	-5.55	-5.48	-5.41
	137.00	-5.97	-5.90	-5.83	-5.76
	141.00	-6.33	-6.26	-6.19	-6.12

Subnasale-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-4.79	-4.65	-4.51	-4.37
	133.00	-5.12	-4.98	-4.84	-4.70
	137.00	-5.45	-5.31	-5.17	-5.03
	141.00	-5.78	-5.64	-5.50	-5.36

Stomion-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-2.55	-2.68	-2.81	-2.94
	133.00	-2.83	-2.96	-1.11	-3.22
	137.00	-3.11	-3.24	-3.37	-3.50
	141.00	-3.39	-3.52	-3.65	-3.78

Menton-Vertex		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-2.68	-2.95	-3.22	-3.50
	133.00	-2.60	-2.88	-3.15	-3.42
	137.00	-2.53	-2.80	-3.07	-3.35
	141.00	-2.45	-2.72	-3.00	-3.27

Table 15. Continued page 5 of 5

Minimum-Frontal Breadth		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-1.25	-0.59	0.06	0.71
	133.00	-0.30	0.36	1.01	1.66
	137.00	0.65	1.31	1.96	2.61
	141.00	1.60	2.26	2.91	3.56

Biocular Breadth		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	1.16	1.81	2.26	2.81
	133.00	1.08	1.63	2.18	2.73
	137.00	1.01	1.56	2.11	2.66
	141.00	0.94	1.48	2.03	2.58

Interpupillary Dist.		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	-2.66	-2.32	-1.97	-1.62
	133.00	-2.59	-2.25	-1.90	-1.55
	137.00	-2.52	-2.18	-1.83	-1.48
	141.00	-2.45	-2.10	-1.76	-1.41

Sellion-Subnasale		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	0.28	0.56	0.84	1.12
	133.00	0.21	0.49	0.77	1.05
	137.00	0.13	0.41	0.69	0.97
	141.00	0.06	0.34	0.62	0.90

Nose Breadth		Sellion-Menton 107.20	110.40	113.60	116.80
Face Breadth	129.00	2.19	1.94	1.68	1.43
	133.00	2.34	2.09	1.84	1.58
	137.00	2.50	2.24	1.99	1.74
	141.00	2.65	2.40	2.14	1.89

Table 16. Estimated Male minus Female Computed Values with Sellion Menton and Bitragion-Submandibular Arc as Dependent Variables

		Sellion-Menton			
Sellion-Tragion		107.20	110.40	113.60	116.80
	268.20	-1.50	-1.46	-1.43	-1.40
Bitrag-Subman Arc	277.40	-2.08	-2.05	-2.01	-1.98
	286.60	-2.66	-2.63	-2.59	-2.56
	295.80	-3.24	-3.21	-3.17	-3.14
		Sellion-Menton			
Subnasale-Tragion		107.20	110.40	113.60	116.80
	268.20	1.92	1.97	2.01	2.05
Bitrag-Subman Arc	277.40	1.68	1.72	1.76	1.81
	286.60	1.43	1.48	1.52	1.56
	295.80	1.19	1.23	1.27	1.32
		Sellion-Menton			
Menton-Tragion		107.20	110.40	113.60	116.80
	268.20	4.86	4.67	4.49	4.30
Bitrag-Subman Arc	277.40	4.47	4.28	4.10	3.91
	286.60	4.08	3.90	3.71	3.53
	295.80	3.69	3.51	3.32	3.14
		Sellion-Menton			
Glabella-Tragion		107.20	110.40	113.60	116.80
	268.20	-1.61	-1.48	-1.34	-1.20
Bitrag-Subman Arc	277.40	-2.25	-2.11	-1.97	-1.83
	286.60	-2.88	-2.74	-2.60	-2.46
	295.80	-3.51	-3.37	-3.24	-3.10

Table 16. Continued page 2 of 6

		Sellion-Menton			
Pronasale-Tragion		107.20	110.40	113.60	116.80
	268.20	0.64	0.86	1.08	1.31
Bitrag-Subman Arc	277.40	0.13	0.35	0.57	0.79
	286.60	-0.39	-0.16	0.06	0.28
	295.80	-0.90	-0.67	-0.45	-0.23

		Sellion-Menton			
Stomion-Tragion		107.20	110.40	113.60	116.80
	268.20	1.98	2.04	2.10	2.16
Bitrag-Subman Arc	277.40	1.76	1.82	1.88	1.95
	286.60	1.54	1.60	1.66	1.73
	295.80	1.32	1.38	1.45	1.51

		Sellion-Menton			
Ectocanthus-Tragion		107.20	110.40	113.60	116.80
	268.20	-0.63	-0.45	-0.27	-0.09
Bitrag-Subman Arc	277.40	-1.69	-1.50	-1.32	-1.14
	286.60	-2.74	-2.56	-2.37	-2.19
	295.80	-3.79	-3.61	-3.43	-3.24

		Sellion-Menton			
Bitragion-Frontal Arc		107.20	110.40	113.60	116.80
	268.20	-1.42	-0.79	-0.15	0.48
Bitrag-Subman Arc	277.40	-1.55	-0.91	-0.28	0.35
	286.60	-1.68	-1.04	-0.41	0.22
	295.80	-1.80	-1.17	-0.54	0.09

		Sellion-Menton			
Bitragion-Menton Arc		107.20	110.40	113.60	116.80
	268.20	-0.44	0.26	0.96	1.66
Bitrag-Subman Arc	277.40	-0.73	-0.03	0.67	1.38
	286.60	-1.02	-0.31	0.39	1.09
	295.80	-1.30	-0.60	0.10	0.80

Table 16. Continued page 3 of 6

		Sellion-Menton			
Face Breadth		107.20	110.40	113.60	116.80
	268.20	0.63	1.06	1.48	1.90
Bitrag-Subman Arc	277.40	-0.39	0.04	0.46	0.88
	286.60	-1.41	-0.99	-0.56	-0.14
	295.80	-2.43	-2.01	-1.58	-1.16

		Sellion-Menton			
Tragion-Wall		107.20	110.40	113.60	116.80
	268.20	1.87	1.27	0.68	0.08
Bitrag-Subman Arc	277.40	2.81	2.21	1.62	1.02
	286.60	3.75	3.15	2.56	1.96
	295.80	4.69	4.09	3.50	2.90

		Sellion-Menton			
Bitragion Breadth		107.20	110.40	113.60	116.80
	268.20	3.24	3.09	2.93	2.78
Bitrag-Subman Arc	277.40	2.17	2.02	1.86	1.71
	286.60	1.10	0.95	0.79	0.64
	295.80	0.03	-0.12	-0.28	-0.43

		Sellion-Menton			
Tragion-Vertex		107.20	110.40	113.60	116.80
	268.20	-0.63	-0.90	-1.17	-1.44
Bitrag-Subman Arc	277.40	0.20	-0.07	-0.34	-0.61
	286.60	1.03	0.76	0.49	0.21
	295.80	1.86	1.59	1.32	1.04

		Sellion-Menton			
Ectocanthus-Vertex		107.20	110.40	113.60	116.80
	268.20	-2.99	-2.83	-2.67	-2.50
Bitrag-Subman Arc	277.40	-2.31	-2.14	-1.98	-1.82
	286.60	-1.62	-1.46	-1.29	-1.13
	295.80	-0.93	-0.77	-0.60	-0.44

		Sellion-Menton			
Glabella-Vertex		107.20	110.40	113.60	116.80
	268.20	-7.08	-6.97	-6.86	-6.76
Bitrag-Subman Arc	277.40	-6.05	-5.94	-5.84	-5.73
	286.60	-5.02	-4.92	-4.81	-4.71
	295.80	-4.00	-3.89	-3.79	-3.68

		Sellion-Menton			
Sellion-Vertex		107.20	110.40	113.60	116.80
	268.20	-5.47	-5.53	-5.59	-5.66
Bitrag-Subman Arc	277.40	-4.88	-4.94	-5.01	-5.07
	286.60	-4.29	-4.36	-4.42	-4.48
	295.80	-3.70	-3.77	-3.83	-3.89

		Sellion-Menton			
Pronasale-Vertex		107.20	110.40	113.60	116.80
	268.20	-8.82	-8.74	-8.66	-8.59
Bitrag-Subman Arc	277.40	-8.14	-8.07	-7.99	-7.92
	286.60	-7.47	-7.39	-7.32	-7.24
	295.80	-6.79	-6.72	-6.64	-6.57

		Sellion-Menton			
Subnasale-Vertex		107.20	110.40	113.60	116.80
	268.20	-7.59	-7.40	-7.20	-7.00
Bitrag-Subman Arc	277.40	-7.28	-7.09	-6.89	-6.70
	286.60	-6.98	-6.78	-6.59	-6.39
	295.80	-6.67	-6.47	-6.28	-6.08

		Sellion-Menton			
Stomion-Vertex		107.20	110.40	113.60	116.80
	268.20	-5.90	-5.98	-6.05	-6.13
Bitrag-Subman Arc	277.40	-5.40	-5.47	-5.55	-5.63
	286.60	-4.89	-4.97	-5.05	-5.13
	295.80	-4.39	-4.47	-4.55	-4.63

Table 16. Continued page 5 of 6

		Sellion-Menton			
Menton-Vertex		107.20	110.40	113.60	116.80
	268.20	-5.12	-5.36	-5.60	-5.84
Bitrag-Subman Arc	277.40	-4.39	-4.63	-4.87	-5.11
	286.60	-3.67	-3.91	-4.15	-4.39
	295.80	-2.95	-3.19	-3.43	-3.67

		Sellion-Menton			
Minimum-Frontal Breadth		107.20	110.40	113.60	116.80
	268.20	-0.32	0.67	1.66	2.65
Bitrag-Subman Arc	277.40	-0.31	0.68	1.67	2.66
	286.60	-0.31	0.68	1.67	2.66
	295.80	-0.30	0.69	1.68	2.67

		Sellion-Menton			
Biocular Breadth		107.20	110.40	113.60	116.80
	268.20	0.47	1.07	1.67	2.27
Bitrag-Subman Arc	277.40	0.67	1.27	1.87	2.47
	286.60	0.87	1.47	2.07	2.67
	295.80	1.07	1.67	2.27	2.87

		Sellion-Menton			
Interpupillary Dist.		107.20	110.40	113.60	116.80
	268.20	-2.74	-2.30	-1.86	-1.43
Bitrag-Subman Arc	277.40	-2.78	-2.34	-1.91	-1.47
	286.60	-2.82	-2.38	-1.95	-1.51
	295.80	-2.86	-2.43	-1.99	-1.55

		Sellion-Menton			
Sellion-Subnasale		107.20	110.40	113.60	116.80
	268.20	0.51	0.89	1.27	1.65
Bitrag-Subman Arc	277.40	-0.01	0.37	0.75	1.13
	286.60	-0.53	-0.15	0.23	0.61
	295.80	-1.05	-0.67	-0.29	0.09

Table 16. Continued page 6 of 6

Nose Breadth		Sellion-Menton			
		107.20	110.40	113.60	116.80
Bitrag-Subman Arc	268.20	1.86	1.67	1.49	1.30
	277.40	1.95	1.77	1.58	1.39
	286.60	2.04	1.86	1.67	1.49
	295.80	2.14	1.95	1.77	1.58