Materials and Methods for NIOSH Anthropometric Data

Sampling Plan

The populations were sampled by age, race, and gender. A stratified sampling plan was used with equal sample sizes in each cell. Each cell was statistically independent, with a sample of 166. The strata consisted of three age strata (18–29, 30–44, 45–66 years), two gender strata (male and female), and four ethnic group strata (White, Black, Hispanic, and Others). The total number of subjects was expected to be 3984. The sample size per cell was determined using the procedures outlined in International Organization for Standardization (ISO) 15535:2003—General Requirements for Establishing Anthropometric Databases. This international standard estimates the sample needed based on the variability in the dimension of interest and its coefficient of variance (CV), the level of precision desired (a), and the level of confidence desired in the resulting database [$n = (1.96 \times CV/a)^2 \times 1.534$]. In this case, the calculations were based on the dimension menton-sellion length. This dimension is one of the important bony dimensions used for respirator design and is also one of the most variable; thus, it presents a worst-case sample size. If the level of precision and confidence is met for menton-sellion length, then it is also met for the other dimensions.

The best estimator for facial dimensions in the United States currently is the Army's 1988 anthropometric survey by Gordon et al. Using the ISO formula, the specific parameters used in the calculation were: 95% confidence and 1% of the mean (1.2 mm) as precision (a = 1). The level of precision was chosen because that is the best level of interobserver error that has been achieved by experienced measurers.(12) Based on the report by Gordon et al., the mean and standard deviation for menton-sellion length were 121.9 mm and 6.5 mm and the dimension of interest and its coefficient of variation (CV) was 5.3%.

Because data from this study were used for both the testing and design of respirators, it was important that the mean value was known with some certainty and that the tails of the distribution were estimated with a 95% confidence level and with the same precision (1% of the mean). Therefore, the ISO formula (with the constant of 1.534) was used so that the sample size was sufficient to calculate the 5th and 95th percentiles with 95% confidence, within plus or minus 1.2 mm. The constant of 1.534 is based on converting the sample size formula from estimating confidence at the mean to estimating confidence at the 5th and 95th percentile (ISO 15535). The calculated sample size per sampling cell using these parameters was 166 [$(1.96 \times CV/a)^2 \times 1.534 = (1.96 \times 5.3/1)^2 \times 1.534 = 166$].

The age division points were somewhat arbitrary but served to ensure that subjects were of a broad age span. The ethnic group "Others" was a diverse group, but not a numerous one. Asians, American Indians, and Alaskan Natives together accounted for only 4.6% of the population according to the 2000 Census. Other races, or combinations of races, were less numerous than that; however, these groups were important because they contained some significant anthropometric variation that needed to be included in the final database. Statistically, the others group was treated like the White, African American, and Hispanic groups. Although the objective was to produce a sample that reflected the distribution of these workers in the U.S. population, racial minorities were deliberately oversampled to ensure adequate variation in race groups. The plan was to weight the race and age categories to accurately reflect the total work force population. This approach allows reweighting in the future should racial proportions in the work force change.

The best way to assure that the required variability in the population was captured was to get as close as possible to full participation in the worksites selected for the study. One method of accomplishing this was to have the measurers circulate among the workers as soon as they arrived at the worksite to encourage participation. The measurers stressed the importance of the study and ensured the workers that the study would take very little time. At some work locations, monetary incentive was provided for participation in the study.

Dimensions Measured

Dimensions were selected to maximize the information that could be obtained from each subject for respirator design and testing. Most dimensions were measured on the face, including minimum frontal breadth and nose breadth, but the remainder of the head was also well represented with head length and breadth measurements. Stature and weight measurements were taken because they form a set of useful basic body descriptors allowing this data set to be compared with others. Neck circumference was added during the data collection when it was learned that it is the primary scaling point for some types of respirators during the development of national and international respiratory protection standards. The full list of measurements that were taken during the study is provided in Table I. The description of each measurement was previously documented (Clauser *et al*.).

TABLE I. Face Dimensions and Landmarks

Dimension	Landmarks	Landmark Positioning
Bigonial breadth	Alare	Right and left
Bitragion chin arc	Cheilion	Right and left
Bitragion coronal arc	Chin	—
Bitragion frontal arc	Ectocanthus	Right and left
Bitragion subnasale arc	Frontotemporale	Right and left
Bizygomatic breadth	Glabella	—
Head breadth	Gonion	Right and left
Head circumference	Infraorbitale	Right and left
Head length	Menton	—
Interpupillary distance	Nasal root point	Right and left
Lip length	Pronasale	—
Maximum frontal breadth	Sellion	—
Menton-Sellion length	Subnasale	—
Minimum frontal breadth	Top of head	—
Nasal root breadth	Tragion	Right and left
Neck circumference	Zygion	Right and left
Nose breadth	Zygofrontale	Right and left
Nose protrusion		
Stature		
Subnasale-Sellion length		
Weight		

Anthropometric Instruments and Software

During the course of the study, traditional anthropometric instruments were used: an anthropometer, a spreading caliper, a sliding caliper (GPM Instruments, Zurich, Switzerland), and a Lufkin steel measuring tape (Cooper Tools, Apex, NC). A data entry and editing software (Anthrotech, 2003; Yellow Springs, Ohio) was used for data collection in the field.

Data Collection Procedures

Prior to conducting the field study, a measurer's handbook was prepared. Included in this guide were illustrated instructions for measuring the dimensions, and a table of values that represented allowable measurement errors for technicians. The allowable errors usually ranged from 1 to 3 mm depending on the dimension measured. The allowable measurement errors were based on work done by Clauser and co-workers for the U.S. Army in 1987 and has become the standard in the field. The measurers practiced with each other until allowable levels of error were reached.

Preliminaries

Potential measuring worksites were identified in a number of ways: the public library, the Internet, and telephone directories to develop lists of potential worksites. Then, these worksites were contacted by phone to invite them to participate in the project. More often than not, the organization or company was interested in helping but did not have the time or energy to participate. When an organization was willing and able to help, a packet of information was sent to explain, in detail, the purposes and protocol of the survey. The partial list of worksites was organized in a reasonable and efficient order according to the proximity of the worksites to each other. Having a list of worksites organized in this way would help to keep travel time and cost to a minimum and would reduce downtime between worksites.

As subjects arrived at the room set aside for measuring, the measurers explained the purposes of the study and the specific protocol to be used. After the explanation, each subject signed a consent form. The subject then filled out the brief demographic questionnaire. The subject number recorded on the questionnaire was a critical element in allowing us to link the demographic and anthropometric data for a given subject. After the paperwork was completed, the subject was ready to be marked and measured.

Landmarking

Landmarks are specific points on the body (in this case the head and face). They are generally, although not always, skeletal points, which are usually marked on the skin overlying the point. For this survey, a series of 26 landmarks was selected in advance (Table I). Most of the landmarks were used to define the traditional measurements (Clauser *et al*.). Subjects were landmarked with a surgical marker or an eyeliner pencil prior to measurement.

Measuring

After landmarking, subjects were measured for each of the dimensions. Data were recorded on data sheets and simultaneously entered into laptop computers. The Anthrotech data entry and editing software evaluated each measurement as it was entered and indicated to the recorder when a measurement value was out of the previously measured range or was otherwise unexpected. In such cases, the measurer repeated the measurement. If the second measurement resolved the initial concern, the second measurement was recorded and the initial measurement discarded. If the anomaly was not resolved, both values were recorded on the electronic data file. Both values were always recorded on the paper data sheet for use in data editing after data collection was completed.

Statistical Analysis

The initial task in preparing traditional (i.e., measured with tape and calipers) anthropometric data was to make sure there were no errors. The first line of defense was the infield data entry and editing system. Despite the efficiency of this system, however, erroneous values could possibly be entered into the database. Therefore, the data were edited again using a combination of regression and outlier identification techniques, such as a high-low distribution. All cases in which an unusual value had been identified in the field were also re-examined at this point. At the final data editing, when regression equations were based on the whole sample, it was always clear which of the two recorded values was correct. Demographic data were edited after entry by examining frequency distributions and identifying unusual values. The unusual demographic values were compared against the original data sheets and were changed to "missing" if they could not be verified.

The second task in preparation of the traditional data was the calculation of the data weights. The sampling strategy called for equal representation in each of the sampling cells. This was done to ensure that the anthropometric variability in all segments of the population was adequately captured. People in the work force do not fall into those cells in equal proportion, however, so the sample needed to be proportionately weighted to be accurately representative of the U.S. work force. Since demographic statistics for the U.S. respirator-wearing population was not available, the sample was weighted to the whole U.S. work force instead.

To calculate the weights, the 2000 U.S. Census data were used and broken down into the same categories as used in the sampling plan. It was assumed that the work force was the total U.S. population between the ages of 18 and 66. Clearly some people in this age range were not in the work force, but there was no reason to believe the work force was anthropometrically distinct from the population as a whole. The weights were calculated as the relative frequency of a given cell in the Census, divided by the relative frequency of the same cell in the present study. It is expressed as:

$$WT_{i,j} = [N_{i,j}/(N_{1,1} + N_{1,2} + \ldots + N_{k,l})]/[n_{i,j}/(n_{1,1} + n_{1,2} + \ldots + n_{k,l})]$$

where

$WT_{i,j}$ is the weight for males or females for age group i and race group j
$N_{i,j}$ is the count from the ith age group and jth race group in the census
$n_{i,j}$ is the count from the ith age group and jth race group in the present study
k is the subscript for the last age group (k = 3)
l is the subscript for the last race group (l = 4)

The sample weights should always be used when calculating any statistics from this database. The sampling and weighting methods used here are consistent with standard practice in anthropometric surveys and in accordance with international standards (e.g., *ISO 15535:2003—General Requirements for Establishing Anthropometric Databases*).

Following the calculation of the weights, the weighted summary statistics were calculated for each measured dimension. In the Army's 1987–1988 anthropometric survey, a number of these same dimensions were collected using the same measurement techniques (Gordon *et al*.). It was interesting

to see how the civilian population data differed from military data. For this comparison, the Army data were weighted to match the current U.S. civilian work force, using the same techniques described above. Both multivariate analysis of variance (MANOVA) and univariate analysis of variance were employed in the comparison. In all multivariate analyses, the Wilks' Lambda was used to calculate the F value. Because the sample size in each survey was very large, the probability of type I error (rejecting the null hypothesis when it is true) for both the multivariate and univariate analyses was high. Therefore, in post hoc analysis, a difference of 2 mm (which is close to measurement error for many dimensions) or greater was required to indicate practical importance.

References

Zhuang, Z. and Bradtmiller, B., 2005. Head-and-Face anthropometrics survey of U.S. respirator users. *Journal of Occupational and Environmental Hygiene*, 2, 567–576.

International Organization for Standardization (ISO): General Requirements for Establishing Anthropometric Databases (ISO 15535). [Standard] Geneva: ISO, 2003.

Gordon, C.C., B. Bradtmiller, C.E. Clauser, et al.: *1987–1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics* (TR-89-044). Natick, Mass.: U.S. Army Natick Research, Development and Engineering Center, 1989.

U.S. Census Bureau: *Census 2000 Basics* by Andrea Sevetson. Washington, D.C.: U.S. Government Printing Office, 2002.

Clauser, C., I. Tebbetts, B. Bradtmiller, J.T. McConville, and C.C. Gordon: *Measurer's Handbook: U.S. Army Anthropometric Survey 1987–1988*. Technical Report/Natick/TR-88/043. Natick, Mass.: U.S. Army Natick Research, Development and Engineering Center, 1988.