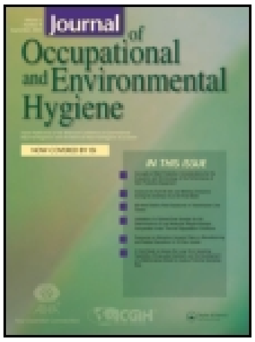

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Head-and-Face Anthropometric Survey of U.S. Respirator Users

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Sizing data generated by the military for use in fitting respirators have been the normative basis for commercial respirator sizing. Anthropometric data developed for males and females of military age in the 1950s and 1960s are still in use today and form the only comprehensive body of information available on this subject. The twofold objective of this study was to: (1) develop an anthropometric database detailing the face size distributions of respirator users using both traditional measurement methods and three-dimensional scanning systems; and (2) use the database to establish fit test panels to be incorporated into the National Institute for Occupational Safety and Health's respirator certification and international standards. A stratified sampling plan was used with three age strata, two gender strata, and four race/ethnic group strata. The plan called for an equal sample size of 166 in each cell. Subjects were obtained at 41 sites from 8 states. In addition to height and weight, 18 facial dimensions and neck circumferences were measured using traditional methods. A total of 3997 subjects were measured using traditional methods, and 1013 of them were also scanned using a 3-D head scanner. As this was a volunteer sample, subjects did not appear in the specific proportions needed for the sampling plan. The resulting data were weighted to correspond to the U.S. population. This article presents the summary statistics for the traditional measurement data only. Multivariate analyses of the data from this study and military data revealed that using historical, military data would be inadequate for describing the anthropometric variability of the current U.S. work force.

Keywords anthropometric survey, face dimensions, fit test panels, respirator sizing

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The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Millions of American workers rely on respirators and other personal protective equipment (PPE) to reduce their risk of disease, injury, and death at work. Although respirators are most commonly used in traditional high-risk industries such as mining, firefighting, construction, and emergency response, they are also used in many other sectors including health care, manufacturing, agriculture, and transportation. Workers depend on respirators not only to reduce risk in highly hazardous circumstances but also for protection in lower risk daily operations. While the use of respirators is mandated in some workplaces, sometimes workers may voluntarily choose to use them for personal health or safety concerns.

According to a survey of private-sector respirator use in the United States, there are 3,303,414 respirator users (who are required to use respirators on the job) employed at 281,776 establishments.[(1)] The National Institute for Occupational Safety and Health (NIOSH) respirator certification program is responsible for ensuring that the respiratory protective devices meet criteria that are assumed to be adequate. Currently, NIOSH is implementing a total inward leakage test to evaluate laboratory respirator protection level as an inherent part of the respirator certification process. Such performance tests require each respirator to be worn by a panel of people. The fit of respirators on this subject panel is assumed to be representative of the fit of respirators on the respirator user populations in the United States. Respirators designed to fit this panel are also expected to accommodate at least 95% of current U.S. civilian workers.

In addition, anthropometric panels of face dimensions are also relied on to provide sizing references in respirator design. The only respirator fit test panels currently available are 25-subject panels developed by Los Alamos National Laboratory (LANL) in the early 1970s.[(2,3)] The LANL panels are based on data from a 1967–1968 survey of young Air Force men and women. The full-facepiece panel was based on the bivariate distribution of face length and face width. The range for face length was 93.5–133.5 mm and the range for face width was 117.5–153.5 mm. The panel was divided into 10 categories representing about 91% of the total U.S. population. The half-facepiece panel was based on the bivariate distribution of the face length and lip length. The range for face length was 93.5–133.5 mm and the range for lip length was 34.5–61.5 mm.

The panel was divided into 10 categories based on a 10-mm increment in face length and a 9-mm increment in lip length, which represented about 95% of the population.

Sizing data generated by the military for use in fitting respirators have been the normative basis for commercial respirator sizing. Anthropometric data developed for males and females of military age in the 1950s and 1960s are still in use today and form the only comprehensive body of information available on this subject. There has long been concern about the applicability of military data and test panels based on military data for civilian workers. The demographics of the U.S. population have changed over the last 30 years. Military personnel have to meet strict entry and fitness criteria and also tend to be younger than the general civilian work force. Military populations may not represent the great diversity in face size in the civilian population because of relatively strict anthropometric armed forces entry requirements and height/weight guidelines for troop retention. Personal protective equipment designed and sized for a military population may not provide the same fitting characteristics for civilian workers because of the greater diversity in body size and shape seen in civilian populations.

There is also scientific evidence indicating the panel applicability problem.[4–6] As early as 1975, Leigh measured 1467 employees (127 of the total were female) of DOW Chemical USA, Rocky Flats Division in Colorado.[4] The anthropometric survey was conducted while employees were fit tested in accordance with the respiratory protection program. Out of the 1467 Rocky Flats employees tested, 10.3% had measurements falling outside the selection area established by the LANL panel for half-mask respirators, and 12.6% had measurements falling outside of the selection area of the LANL panel for full-facepiece respirators. It was concluded that a change in the LANL panel selection area would be advantageous.

The U.S. Bureau of Mines surveyed 48 male mine rescue workers in 1978.[5] That study suggested a more extensive survey of the industrial populations who used PPE was required. In a recent NIOSH study,[6] the manual measurements of 2391 civilian subjects (only two face dimensions, length and width, were measured) from the project titled "Civilian American and European Surface Anthropometry Resource (CAESAR)," were analyzed. The CAESAR data were used to determine if the military data were appropriate for civilian workers. The LANL panel for full-facepiece respirators was found to include only 84% of the CAESAR subjects. Thus, fit test panels representative of today's workers need to be developed to ensure that NIOSH's assessment of respirator performance characteristics can be as representative as possible.

While there have been many comprehensive anthropometric surveys of military populations over the years, surveys involving civilian populations have been rare. In the United States, the last government-conducted comprehensive survey of civilian adults was a survey of women by the Department of Agriculture in 1939.[7] The measurements in that survey were for clothing applications and did not include facial measurements. In addition, a handful of measurements were taken in the Health and Nutritional Examination Studies done by the National Center for Health Statistics.[8] With the exception of the 1960–1962 study by Stoudt et al.,[9] these studies have focused on providing only health-related data and not on obtaining design data. Indeed, even the Stoudt et al. study had only a handful of measurements, and these focused on workstation or vehicle-type applications rather than measurements that would be useful in respirator design. The first face measurement of a civilian population was in Australia in 1972.[10]

In 2001, the NIOSH National Personal Protective Technology Laboratory recognized the difficulties inherent in using the old military data and initiated a study to develop an anthropometric database of the heads and faces of civilian respirator users. The requirement was that the database should be representative of the demographic variability in the United States and should include respirator users from all segments of the user population. These population groups included users in various types of industry, health care, and emergency response. A new anthropometric database could then be used to develop new respirator fit test panels.

A secondary objective was to collect three-dimensional (3-D) scans of a subset of the sample. While methods for using these data are not standardized, the data collection method is standard, and the resulting 3-D data can be used in a variety of applications. The 3-D data enable NIOSH and other researchers to explore the relationship between facial shapes and contours, and the shapes and contours of respirators. The new face dimension data and state-of-the-art 3-D head scanner can be used for evaluating face shape characteristics and designing respirators with improved face-fitting characteristics. It is well known that workers are less likely to wear personal protection systems of any kind if the systems are uncomfortable or do not fit well.

Information generated by this study can benefit: (1) workers exposed to various gases and aerosols by providing fit test panels that accurately represent today's workers; and (2) those involved in testing, certifying, and manufacturing respirators to be used in industry by providing them with fit test panels for evaluating air-purifying respirator facepiece fit characteristics.

This article presents the summary statistics for the traditional measurement data.

METHODS AND MATERIALS

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.*[11] 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.[12] 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.,[12] 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.[11] 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.[13] 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.[14]

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, N.C.).

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		

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[14] 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.[14] 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 in-field 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

TABLE II. Final Sample by Sampling Cell

	Male Age Group				Female Age Group			
Race	18–29	30–44	45–66	Total	18–29	30–44	45–66	Total
White	271	611	485	1367	151	194	174	519
African American	101	255	278	634	51	213	325	589
Hispanic	155	182	75	412	53	36	37	126
Other	24	47	59	130	52	65	103	220
Total	551	1095	897	2543	307	508	639	1454

TABLE III. Weights by Sampling Cell

	Male Age Group			Female Age Group		
Race	18–29	30–44	45–66	18–29	30–44	45–66
White	1.516531	1.070699	1.473671	1.502991	1.881647	2.407866
African American	0.835324	0.424599	0.312164	1.000204	0.324416	0.181680
Hispanic	0.808564	0.691170	0.933218	1.124507	1.823606	1.150489
Other	2.332153	1.338566	0.741441	0.597626	0.566132	0.265141

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.[13] 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:

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

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.[12] 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.

RESULTS

Table II shows the final sample by sampling cell. The weights are summarized for each cell in Table III. The goals in some sampling cells were surpassed and, in others,

TABLE IV. Final Sample by Geographic Region

State	N	%
California	229	5.7
Illinois	1563	39.1
Kentucky	93	2.3
New York	120	3.0
Ohio	751	18.8
Pennsylvania	29	0.7
Texas	857	21.4
Virginia	355	8.9
Total	3997	100.0

TABLE V. Final Sample by Type of Workplace

	Male		Female		Total	
Occupation	N	%	N	%	N	%
Construction	594	23.4	47	3.2	641	16.0
Fire Fighting	774	30.4	74	5.1	848	21.2
Health Care	381	15.0	1100	75.7	1481	37.1
Law Enforcement	121	4.8	7	0.5	128	3.2
Manufacturing	429	16.9	60	4.1	489	12.2
Others	244	9.6	166	11.4	410	10.3
Total	2543	100.0	1454	100.0	3997	100.0

not quite met. By weighting the final sample, the summary anthropometric statistics provided below are accurate for the population, even though the sampling goals were not met in some cells.

The distribution of subjects across geographic locations can be seen in Table IV. The intent was to sample more or less evenly across the geographic regions. In practice, this was made difficult by widely varying levels of cooperation

TABLE VI. Anthropometric Summary Statistics by Sex

	N	Mean	Std. Dev.[A]	Skewness	Kurtosis	Min	Max
			Males				
Dimension							
Bigonial breadth	2543	120.4	10.4	0.442	−0.013	90	160
Bitragion chin arc	2543	331.2	15.5	0.096	0.146	271	393
Bitragion coronal arc	2543	350.7	13.9	0.097	−0.054	310	405
Bitragion frontal arc	2543	304.1	13.0	0.090	0.128	263	349
Bitragion subnasale arc	2543	294.8	13.2	0.141	0.079	253	345
Bizygomatic breadth	2542	143.5	6.9	0.144	0.014	120	170
Head breadth	2543	153.0	6.0	0.151	0.320	135	179
Head circumference	2543	575.7	17.1	0.108	0.311	520	639
Head length	2543	197.3	7.4	−0.048	0.041	174	225
Interpupillary distance	2543	64.5	3.6	0.189	0.040	53	79
Lip length	2543	51.1	4.2	0.125	−0.069	40	70
Maximum frontal breadth	2543	112.3	5.5	0.156	−0.018	95	131
Menton-Sellion length	2543	122.7	7.0	0.077	0.059	100	156
Minimum frontal breadth	2543	105.5	5.7	0.133	−0.043	90	127
Nasal root breadth	2543	16.6	2.3	0.196	0.223	10	29
Neck circumference	1023	406.7	32.6	0.542	0.906	312	570
Nose breadth	2543	36.6	4.1	0.780	0.867	26	58
Nose protrusion	2543	21.1	2.7	0.178	0.054	13	32
Stature	2543	1753.9	67.7	−0.020	−0.054	1488	2012
Subnasale-Sellion length	2543	52.0	4.1	0.092	−0.161	40	66
Weight	2540	90.4	17.5	0.692	0.690	42.9	167.8

	1	2	5	10	20	25	30	40	50	60	70	75	80	90	95	98	99
									Males, percentiles								
Dimensions																	
Bigonial breadth	101	102	105	108	111	113	115	116	120	122	125	127	130	135	140	145	147
Bitragion chin arc	297	300	306	311	318	320	323	326	330	335	340	340	345	350	355	364	370
Bitragion coronal arc	320	322	330	333	340	340	344	346	350	355	359	360	362	370	375	380	385
Bitragion frontal arc	275	280	282	290	295	295	297	300	305	307	310	312	315	320	326	333	335
Bitragion subnasale arc	265	269	275	279	285	285	288	290	295	298	301	305	305	312	315	322	328
Bizygomatic breadth	130	130	132	135	137	139	140	142	143	145	147	148	150	152	155	158	160
Head breadth	140	141	144	145	148	150	150	151	153	154	155	157	158	161	163	165	167
Head circumference	536	540	547	555	562	565	566	571	575	580	584	586	590	597	604	613	618
Head length	180	181	185	187	191	192	194	195	197	200	201	202	203	206	210	212	215
Interpupillary distance	57	58	59	60	62	62	63	64	65	66	67	67	68	69	71	73	74
Lip length	42	43	44	46	47	48	49	50	51	52	53	54	55	56	58	60	61
Maximum frontal breadth	100	101	104	105	108	109	110	111	112	114	115	116	117	120	122	124	126
Menton-Sellion length	107	109	111	114	117	118	119	121	123	125	126	127	129	131	135	137	139
Minimum frontal breadth	92	94	95	99	100	101	102	104	105	107	109	110	110	113	115	118	120
Nasal root breadth	12	12	13	14	15	15	15	16	16	17	18	18	18	19	20	21	22
Neck circumference	340	345	355	370	380	385	390	396	403	410	420	425	432	450	465	485	502
Nose breadth	29	30	31	32	33	34	34	35	36	37	38	39	40	42	45	47	48
Nose protrusion	15	16	17	18	19	19	20	20	21	22	22	23	23	25	26	27	28
Stature	1597	1613	1642	1667	1697	1709	1719	1737	1754	1771	1790	1800	1809	1842	1866	1894	1911
Subnasale-Sellion length	43	44	45	47	48	49	50	51	52	53	54	55	55	57	59	60	62
Weight	57.9	61.1	65.7	69.7	75.8	78.3	80.3	84.4	88.4	92.5	97.8	100.1	103.4	113.9	122.7	134.8	140.3

TABLE VI. Anthropometric Summary Statistics by Sex *(Continued)*

	N	Mean	Std. Dev.^{A}	Skewness	Kurtosis	Min	Max
				Females			
Dimension							
Bigonial breadth	1454	110.1	8.9	0.646	0.847	88	150
Bitragion chin arc	1454	303.9	14.9	0.179	0.499	248	375
Bitragion coronal arc	1454	339.3	15.0	0.026	0.268	290	425
Bitragion frontal arc	1454	287.4	11.9	0.082	0.156	250	330
Bitragion subnasale arc	1454	277.5	13.1	0.307	0.383	238	335
Bizygomatic breadth	1454	135.1	6.5	0.174	0.184	115	157
Head breadth	1454	146.8	5.6	−0.010	0.307	129	165
Head circumference	1454	554.9	17.8	0.230	1.014	475	654
Head length	1454	187.5	7.2	−0.201	0.531	152	215
Interpupillary distance	1452	61.9	3.5	0.281	0.395	52	78
Lip length	1454	48.0	4.0	0.230	−0.116	35	63
Maximum frontal br	1454	108.6	5.3	0.094	−0.103	92	130
Menton-Sellion length	1454	113.4	6.1	0.130	−0.042	91	135
Minimum frontal breadth	1454	102.9	5.4	−0.004	−0.046	84	126
Nasal root breadth	1454	16.3	2.0	0.033	0.225	10	25
Neck circumference	793	339.5	30.9	0.903	1.999	260	505
Nose breadth	1454	33.2	3.9	0.894	0.947	22	54
Nose protrusion	1454	19.8	2.7	0.281	0.154	11	29
Stature	1454	1625.4	67.5	0.058	0.466	1310	1862
Subnasale-Sellion length	1454	48.2	3.8	0.209	−0.080	32	59
Weight	1448	75.7	18.7	0.849	0.544	34.2	176.4

	1	2	5	10	20	25	30	40	50	60	70	75	80	90	95	98	99
									Females, percentiles								
Dimensions																	
Bigonial breadth	93	95	98	100	102	104	105	107	110	111	114	115	117	122	125	131	136
Bitragion chin arc	270	275	280	285	290	295	295	300	305	307	311	313	315	322	328	338	342
Bitragion coronal arc	305	305	315	320	326	330	330	335	340	344	346	350	352	358	365	370	375
Bitragion frontal arc	260	265	270	271	277	280	280	285	287	290	295	295	298	302	305	312	320
Bitragion subnasale arc	249	252	258	260	267	269	270	275	277	280	284	285	288	295	300	305	313
Bizygomatic breadth	121	122	124	127	130	131	132	133	135	136	138	140	140	144	146	149	152
Head breadth	133	135	137	140	142	143	144	145	146	148	150	150	151	154	156	159	161
Head circumference	515	520	527	533	540	544	546	550	555	558	563	565	569	578	585	594	604
Head length	170	172	175	178	182	183	184	186	187	190	191	192	194	196	199	202	205
Interpupillary distance	55	55	56	58	59	60	60	61	62	63	64	64	65	67	68	69	71
Lip length	40	40	42	43	44	45	46	47	48	49	50	51	51	53	55	57	58
Maximum frontal breadth	97	98	100	102	104	105	106	107	108	110	111	112	113	115	117	120	121
Menton-Sellion length	100	102	104	106	108	109	110	112	113	115	116	118	119	121	124	126	128
Minimum frontal breadth	90	91	94	96	99	100	100	101	103	105	106	106	107	110	111	114	115
Nasal root breadth	12	12	13	14	15	15	15	16	16	17	17	18	18	19	20	21	21
Neck circumference	285	290	295	305	313	320	321	330	335	343	352	357	365	380	395	415	425
Nose breadth	26	27	28	29	30	31	31	32	33	33	34	35	36	39	41	43	45
Nose protrusion	14	15	16	16	17	18	18	19	20	20	21	21	22	23	25	26	27
Stature	1479	1493	1513	1538	1570	1580	1590	1609	1627	1643	1660	1669	1680	1709	1731	1770	1794
Subnasale-Sellion length	40	41	42	44	45	46	46	47	48	49	50	51	51	53	55	57	58
Weight	44.5	48.4	51.8	54.5	59.7	61.6	63.6	67.6	72.1	76.9	82.8	86.8	91.5	102.5	112.1	123.0	126.7

Note: Respirator sample weighted to represent U.S. population aged 18–66 (weight in kg, all other values in mm).
^{A}Std. Dev. = standard deviation.

from survey sites. The result was that more subjects from the Midwest and Texas were measured than from other geographic areas. Since there is no evidence that geographic location affects face size and shape (after race and age are taken into account), this apparent disparity is not a problem.

The distribution of subjects among type of workplace is shown in Table V. There was no requirement to sample equally across these workplace types. It was only important that all types of workplaces where respirators were used were well represented.

TABLE VII. NIOSH Respirator Data Versus U.S. Army Data by Sex

	NIOSH Respirator Sample (Weighted)					U.S. Army Sample (Weighted)					
Dimension	N	Mean	Std. Dev.[A]	Min	Max	N	Mean	Std. Dev.[A]	Min	Max	Stat. Sig.[B]
					Males						
Bigonial breadth	2543	120.4	10.4	90	160	1774	121.7	9.4	88	154	0.000
Bitragion chin arc	2543	331.2	15.5	271	393	1774	328.4	13.5	278	372	0.000
Bitragion coronal arc	2543	350.7	13.9	310	405	1774	353.1	12.6	299	395	0.000
Bitragion frontal arc	2543	304.1	13.0	263	349	1774	305.4	10.3	271	348	0.000
Bitragion subnasale arc	2543	294.8	13.2	253	345	1774	292.6	10.9	255	328	0.000
Bizygomatic breadth	2542	143.5	6.9	120	170	1774	141.9	5.3	118	161	0.000
Head breadth	2543	153.0	6.0	135	179	1774	153.6	5.3	128	173	0.001
Head circumference	2543	575.7	17.1	520	639	1774	570.9	15.5	514	627	0.000
Head length	2543	197.3	7.4	174	225	1774	196.8	6.9	173	220	0.026
Interpupillary distance	2543	64.5	3.6	53	79	1772	64.9	3.0	52.0	78.0	0.000
Lip length	2543	51.1	4.2	40	70	1774	57.4	4.0	44	71	0.000
Maximum frontal breadth	2543	112.3	5.5	95	131	1774	112.9	4.5	95	134	0.000
Menton-Sellion length	2543	122.7	7.0	100	156	1774	122.2	6.5	101	148	0.025
Minimum frontal breadth	2543	105.5	5.7	90	127	1774	105.0	4.8	82	127	0.003
Neck circumference	1023	406.7	32.6	312	570	1774	385.2	26.8	316	470	0.000
Nose breadth	2543	36.6	4.1	26	58	1774	36.4	3.7	26	53	0.132
Nose protrusion	2543	21.1	2.7	13	32	1774	19.5	2.4	11	29	0.000
Stature	2543	1753.9	67.7	1488	2012	1774	1747.3	70.7	1497	2042	0.002
Subnasale-Sellion length	2543	52.0	4.1	40	66	1774	51.0	3.9	37	63	0.000
Weight	2540	90.4	17.5	43	168	1774	81.4	13.5	47.6	127.8	0.000
					Females						
Bigonial breadth	1454	110.1	8.9	88	150	2208	109.4	7.3	87	144	0.013
Bitragion chin arc	1454	303.9	14.9	248	375	2208	302.1	12.2	261	350	0.000
Bitragion coronal arc	1454	339.3	15.0	290	425	2208	336.0	13.0	298	392	0.000
Bitragion frontal arc	1454	287.4	11.9	250	330	2208	287.2	9.6	250	320	0.522
Bitragion subnasale arc	1454	277.5	13.1	238	335	2208	274.4	9.9	242	315	0.000
Bizygomatic breadth	1454	135.1	6.5	115	157	2208	132.3	5.4	117	150	0.000
Head breadth	1454	146.8	5.6	129	165	2208	145.6	5.2	126	167	0.000
Head circumference	1454	554.9	17.8	475	654	2208	546.5	14.3	500	611	0.000
Head length	1454	187.5	7.2	152	215	2208	186.7	5.8	158	211	0.000
Interpupillary distance	1452	61.9	3.5	52	78	2204	61.7	3.3	52.0	76.0	0.037
Lip length	1454	48.0	4.0	35	63	2208	55.1	3.9	41	69	0.000
Maximum frontal breadth	1454	108.6	5.3	92	130	2208	111.1	5.0	92	134	0.000
Menton-Sellion length	1454	113.4	6.1	91	135	2208	113.1	5.9	95	134	0.101
Minimum frontal breadth	1454	102.9	5.4	84	126	2208	103.5	4.5	86	121	0.002
Neck circumference	793	339.5	30.9	260	505	2208	314.7	13.9	272	372	0.000
Nose breadth	1454	33.2	3.9	22	54	2208	33.4	3.9	23	50	0.145
Nose protrusion	1454	19.8	2.7	11	29	2208	18.9	2.4	11	25	0.000
Stature	1454	1625.4	67.5	1310	1862	2208	1619.1	55.5	1428	1870	0.003
Subnasale-Sellion length	1454	48.2	3.8	32	59	2208	48.9	3.8	34	65	0.000
Weight	1448	75.7	18.7	34	176	2208	63.6	8.5	41.3	96.7	0.000

Note: Weight in kg for means and standard deviations for selected dimensions; all other values in mm.
[A] Std. Dev. = standard deviation.
[B] Stat. Sig. = statistical significance.

The summary anthropometric statistics are shown in Table VI, for males and females, separately. In most cases, work force populations are not evenly split between the sexes. This is certainly true in the subpopulation that wears respirators. For example, users in the health professions tend to be mostly female; those in construction tend to be mostly male. Firefighters and law enforcement officers are generally male, and so on. Therefore, it is better to provide summary data for males and females separately.

The comparisons of NIOSH data and Army data for selected dimensions are shown in Table VII. The significance levels in the table refer to univariate independent sample t-tests. As would be expected, the civilian sample with a full age range was different from the relatively young and fit military sample. The biggest differences were in weight, and the dimensions such as neck circumference that have some relationship to weight. The means for menton-sellion length, which was used to define LANL respirator fit test panels, differed by less than 1 mm for both males and females.

Statistical significance, however, is affected by large sample sizes, and that small differences, although of statistical significance, have no practical importance. The other dimensional difference that would appear to be of practical importance was lip length. In fact, this was a measurement artifact. In the Army survey, lip length was measured using an automated headboard device that employed a digital touch probe. It appeared that there were differences between the way the probe touched the corner of the lip and the way the caliper touched the corner of the lip.

A multivariate analysis of variance was also performed to test whether the two groups (Army and the current sample) could be distinguished multivariately. On all statistical tests (Pillai, Wilks, etc.), the two samples were significantly different. This is not an unexpected result, given the large sample size in both groups. The comparison confirmed the initial suspicions that using historical military data would be inadequate for describing the anthropometric variability of the current U.S. work force.

DISCUSSSION

This study provided information regarding the face dimensions of civilian respirator users for design and sizing applications. In all, the sample can be seen to have captured the demographic, geographic, and occupational variability of the nation's respirator users. A data source that would identify the distribution of all U.S. respirator users, specifically, across these demographic areas of interest was not available. Thus, for purposes of calculating summary anthropometric statistics, this data set was weighted to reflect the U.S. work force as a whole. If the appropriate demographic data for respirator users are available in the future, the data set can easily be re-weighted to reflect the new information.

This study also laid the groundwork for many other studies. The dimensions are critical to the design and sizing of respirators. This database can be viewed as a normative database characterizing the variability of people for the cost effective design of just about anything people wear on their head and face.

A companion study was conducted to evaluate the ability of the current respirator fit test panels, developed by the Los Alamos National Laboratory (LANL) in 1973, to represent the current U.S. civilian workers.[15] That study found that the LANL full-facepiece panel excluded 15.3% of NIOSH survey subjects. Subjects in the NIOSH survey had greater key face dimensions (face length and face width) than the subjects in the 1967–1968 USAF survey. Thus, it was recommended that the LANL respirator fit test panels be revised.

New respirator fit test panels have now been developed and are reported in a companion paper. It is anticipated that these panels will be useful for years to come.

CONCLUSIONS

It has been decades since the LANL respirator fit test panels were created. They have never been previously updated. In the time since they were created, the nation's work force has changed, and the LANL fit test panels are no longer representative of the nation's respirator users.

This study responded to that need by creating the largest anthropometric database on civilian heads and faces in U.S. history. A total of 3997 respirator users were measured. Dimensions were chosen to maximize their utility in the design and testing of new respiratory protection equipment. Multivariate analyses of the data from this study and military data revealed that using historical military data would be inadequate for describing the anthropometric variability of the current U.S. work force.

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