Evaluating the Representativeness of the LANL Respirator Fit Test Panels for the Current U.S. Civilian Workers

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ABSTRACT

This study evaluated 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. The 1967 and 1968 U.S. Air Force (USAF) anthropometric survey data of 4325 military persons (on which the LANL fit test panels were based) and the 2003 National Institute for Occupational Safety and Health (NIOSH) survey of 3998 civilian respirator users (weighted to match the 2000 U.S. census population) were used in the study. Comparisons were made on age and race distributions as well as key face dimensions (face length, face width and lip length) between the USAF and NIOSH surveys. Age and race distributions of the USAF data were different from those of the NIOSH data. Significant differences in key face dimensions were found among different age and racial/ethnic groups within the NIOSH survey. The bivariate distribution of face length and face width for full-face-piece applications and the face length and lip length for half-face-piece applications were different between the two surveys. Furthermore, the LANL full-face-piece panel excluded 15.3 percent of NIOSH survey subjects. It can be concluded that the LANL respirator fit test panels do not represent the current U.S. civilian workforce well. The newly available NIOSH data can be used to revise respirator fit test panels.

Keywords: Respirator, Face Dimensions, Fit Test Panels, Sizing

INTRODUCTION

Anthropometric panels of face dimensions are often relied upon to provide sizing references in respirator design and certification testing. The current anthropometric panels for the American industrial workers were developed by the Los Alamos National Laboratory (LANL, formerly Los Alamos Scientific Laboratory) on the basis of the 1967 and 1968 U.S. Air Force (USAF) survey of in-service men and women (Hack *et al.* 1973; Hack & McConville, 1978). Since 1973, these panels have played a prominent role in the United States. The face anthropometry of these subject panels is assumed to be representative of the face anthropometry of the respirator user populations. Respirators designed to fit these panels are expected to accommodate at least 95% of U.S. workers.

Because these panels were based on military data, concern has been raised about compatibility with civilian populations (Liau *et al.* 1982, Stein 1978). Military anthropometric data may not represent civilian data because of homogeneity of the data collected in the late 1960s. To date, there have been only two surveys devoted to the comparison of the military-civilian differences in face dimensions and the sample size involved in each study was small. The 1972 Los Alamos survey consisted of 200 male subjects (Hack *et al.*, 1973, Hack & McConville, 1978) and the U.S. Bureau of Mines (BOM) survey consisted of 48 male mine rescue workers (Stein 1978). A large-scale survey of civilian face anthropometry was clearly needed to determine if the military-civilian differences are of practical significance. The recent completion of the National Institute for Occupational Safety and Health (NIOSH) anthropometric survey of respirator users made it possible to effectively assess the military-civilian difference (Zhuang, *et al.*, 2004).

In addition to the military-civilian differences, the ability of the LANL fit test panels to represent U.S. industrial workers may have diminished because of demographic changes of the United States over the last 30 years. Among the most noticeable changes were an increase of workers from minority groups and an influx of women in the workforce. These demographic changes may have had an important influence on the anthropometry of face dimensions of the civilian industrial population.

The present study examined the effects of military-civilian differences and demographic changes (age and race/ethnicity) on face dimensions used for defining the LANL respirator fit test panels. Specifically, this study compared the age and race distributions of the two surveys (1967-1968 U.S. Air Force survey and 2003 NIOSH survey), analyzed the distributions of face length, face width and lip length using multivariate statistical methods, and evaluated the ability of the LANL full- and half-facepiece panels to accommodate a specified proportion (90% - 95%) of the current civilian population.

History of the Development of the LANL Test Panels

In the early 1970s, the Respirator Research and Development Section of the LANL was asked by NIOSH to develop anthropometric specifications for fit testing of full- and half-facepiece respirators. Because no survey of face dimensions of the U.S. workers was available at that time, the LANL team decided to develop these specifications based on the 1967 and 1968 USAF anthropometric survey (Kennedy, 1986; Clauser *et al.*, 1972). Prompted by concerns over the possible incompatibility of military and civilian data, the Los Alamos team surveyed 200 civilians on 13 face dimensions, including menton-nasal root depression length (face length), bizygomatic breath (face width) and lip length - three face dimensions critical for the development of respirator fit test panels. The survey found close agreement to approximately 2 mm between the USAF and Los Alamos surveys. Therefore, it was concluded that the USAF survey could be used for the development of fit test panels that represented the face dimensions of U.S. industrial workers.

The full-facepiece panel was based on the bivariate distribution of face length and face width (Hack, *et al.*, 1973; Hack and McConville, 1978). The upper limit of the panel was defined by the mean value of male population plus two standard deviations and the lower limit was defined by the mean value of the female population minus two standard deviations. The resulting range for face length was 93.5 - 133.5 mm and face width was 117.5-153.5 mm. The panel was then divided into 16 categories, based on a 10-mm increment in face length and a 9-mm increment in face width. Because six cells contained very low percentages of the population (<0.1% - 1.8%), they were deleted from the panel, leaving a 10-category panel representing about 91% of the total population. Twenty-five subjects were selected for the panel size, as suggested by NIOSH as a practical limit of expense and time to perform tests. The number of subjects for each cell was determined based on the percentage of the USAF survey populations for that cell. Thus, the test panel is usually referred to as the 25-member panel for testing of respirators.

The half-facepiece panel was based on the bivariate distribution of the face length and lip length (Hack, *et al.*, 1973; Hack and McConville, 1978). The upper and lower limits were defined in the same way as it was for the full-facepiece panel. The resulting range for face length was 93.5 - 133.5 mm, and lip length was 34.5 - 61.5 mm. The panel was divided into 12 categories, based on a 10-mm increment in face length and a 9-mm increment in lip length. Because two cells contained very low percentages of the

population (0.2% - 0.3%), they were deleted from the test panel, leaving a 10-category panel that represented about 95% of the population. Twenty-five subjects were selected as the panel size and the number of subjects for each cell was determined based on the percentage of the USAF survey populations for that cell.

Both the full- and half-facepiece panels have been used as anthropometric specifications for respirator fit testing ever since they were developed in 1973. In a typical test, 25 subjects are recruited according to the face dimension criteria in the LANL panels for half- and full-facepiece respirators. The original pass/fail criteria for the panel suggested that a single respirator model that was designed to fit 95% of the user population should have only a single failure of the 25 subjects tested (Hack, *et al.*, 1973).

MATERIALS AND METHODS

Materials

Two anthropometric surveys were involved in the present analysis: the 1967-1968 USAF anthropometric survey (Kennedy, 1986; Clauser *et al.*,1972) and the 2003 NIOSH survey. The USAF survey was conducted by the Anthropology Branch of the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base. The survey consisted of 2420 male flyers (mean age: 30; SD: 6.3) measured for 188 body dimensions including 46 head and face dimensions and 1905 enlisted woman (mean age: 22.9; SD: 6.5) measured for 137 body dimensions including 46 head and face dimensions.

The 2003 NIOSH survey was a nationwide anthropometric survey of respirator users (Zhuang *et al.*, 2004). The subjects were recruited from various industries, including manufacturing, construction, health care, law enforcement, and firefighting. These workers rely on respirators to prevent work-related respiratory illnesses and injuries. A stratified sampling plan was used with an equal sample size of 166 in each cell. The survey consisted of three age strata (18-29, 30-44, 45-65 years), two gender strata (male and female), and four racial/ethnic group strata (White, African American, Hispanic, and Others). Height, weight, 18 face dimensions and neck circumference were measured with traditional methods. A total of 3,997 subjects (2,543 male and 1,454 female) were measured using anthropometric calipers.

In addition to the two anthropometric surveys, the 2000 U.S. census (U.S. Census Bureau, 2002) was used in the analysis of age and race distributions of U.S. civilian population in comparisons to the distribution of 1967-1968 Air Force survey. The 2000 U.S. census is a complete enumeration of population and housing taken by the Census Bureau as of April 1, 2000. A limited number of questions were asked of every person and housing unit. Information is available on: name, household relationship, sex, age, Hispanic or Latino origin, race, and tenure (whether the home is owned or rented). The present analysis was based upon the demographic information on age, sex and race distribution of the 2000 U.S. census data.

Analysis of Data

Statistical analysis was performed by using the Statistical Analysis System (SAS®) software (SAS Institute Inc., 1999). Analysis of data consisted of four steps. Step 1 focused on the analysis of age and race distributions of the USAF survey, the NIOSH survey, and the 2000 U.S. census. The USAF and NIOSH surveys did not include any individual younger than 18. To be consistent, any individual in the 2000 census whose age was below 18 was excluded from the analysis of age distribution.

Step 2 focused on the analysis of the bivariate distribution of face length and face width and the bivariate distribution of face length and lip length in the USAF and NIOSH surveys. Both multivariate analysis of variance (MANOVA) and univariate analysis of variance were employed in these analyses. 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 is 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 (Gordon *et al.*, 1989).

Step 3 focused on the effects of age and race/ethnicity on face length, face width, and lip length in the NIOSH survey. Multivariate and univariate analyses of variance were employed in this step.

Step 4 examined the ability of the full- and half-facepiece panels to accommodate a specified (95%) proportion of the NIOSH survey population by fitting data from the NIOSH survey into the LANL full- and half-facepiece panels. For the full-facepiece panel, data on face length and face width were fit into the ten cells of the full-facepiece panel. Any individual whose bivariate dimensions (face length and face width) fell outside the boundaries of the panel was excluded. The count and percentage were calculated for men, women and total (men and women), respectively, in each cell. Then, the rate of acceptance was used to represent the ability of the panel to accommodate the specified proportion (95%) of the NIOSH survey population. For the half-facepiece fit test panels, data on face length and lip length were used, and the procedure was repeated.

RESULTS

Distributions of Age and Race

Tables I and II compare the distributions of age and race-ethnicity of the afore-mentioned USAF and NIOSH anthropometric surveys with that of the 2000 U.S. census. The USAF survey was dominated by age groups 18-29 and 30-44. In particular, the age group of 18-29 represented more than half of the total population in the survey. The 45-year-and-over group represented less than 2 percent of the total population in the survey (Table I). It is obvious that the USAF survey does not match the age distribution of the current U.S. civilian population. In contrast, the age distribution of the NIOSH data corresponded to that of the 2000 U.S. census much better.

It is clear that the race distribution of the 2000 U.S. census was more diversified than the 1967-68 USAF surveys (Table II). While Caucasian men represented 97.8% of all men surveyed and Caucasian women 91.4% of all women surveyed, the 2000 U.S. census showed that Caucasian men and women represented 70.0% and 69.6%, respectively. In addition, while African American men represented 1.1% and African American women 7.7 % in the USAF survey, they represented 11.0% and 12.3%, respectively, in the 2000 U.S. census. These statistics indicate that the 1967-68 USAF survey, upon which the LANL fit test panel was based, does not match the 2000 U.S. census in race distribution.

Table I. Age Distribution of the U.S. Air Force Survey, NIOSH Survey, and the 2000 Census

Age Groups	USAF (%)		NIOSH (%)		2000 Census (%)	
	Male (n=2420)	Female (n=1905)	Male (n=2544)	Female (n=1454)	Male	Female
45-66	1.3	1.4	35.3	44.3	36.0	37.7
30-44	41.6	11.3	43.0	34.9	37.4	37.0
18-29	57.1	87.3	21.7	21.1	26.6	25.3

The 2003 NIOSH survey represented a racially diversified population. It was not designed to match the distribution of the 2000 U.S. census. However, the racially diversified strategy enabled researchers to give weight to each subject to match the distribution of the 2000 U.S. census. The weighing factors are summarized in Table III.

Table II. Race Distribution of the U.S. Air Force Survey, NIOSH Survey, and the 2000 Census

Race-Ethnicity	USAF (%)		NIOSH (%)		2000 Census (%)	
	Male (n=2420)	Female (n=1905)	Male (n=2544)	Female (n=1454)	Male	Female
Caucasian	97.7	91.4	53.8	35.7	70.0	69.6
African American	1.1	7.7	24.9	40.5	11.0	12.3
Hispanic	NA	NA	16.2	8.7	12.6	11.5
Others	1.2	0.9	5.1	15.1	6.4	6.6

Table III. Weighting Factors (Fraction of a Race/Age Group in U.S. Population Divided by the Fraction of the Same Group in the Sample)

Race	Male			Female		
	Age Group			Age Group		
	18 – 29	30 - 44	45 – 66	18 – 29	30 - 44	45 – 66
Caucasian	1.517	1.069	1.474	1.502	1.890	2.406
African American	0.836	0.425	0.312	1.000	0.324	0.182
Hispanic	0.809	0.691	0.934	1.124	1.822	1.150
Other	2.333	1.339	0.742	0.597	0.566	0.265

Bivariate Distribution of Face Length and Face Width

Table IV presents the summary statistics on the face length and face width from the USAF surveys and NIOSH survey. As the table indicates, the mean differences in the bivariate distribution of face length and face width between the two surveys were generally greater for women than for men. On face length, the difference was 2.4 mm for men whereas it was 7.2 mm for women. On face width, the difference was 1.2 mm for men whereas the difference was 6.1 mm for women.

Table IV. Weighted Summary Statistics for Face Length, Face Width and Lip Length by Survey

Face Dimensions	Survey	Male		Female	
		Mean (mm)	SD	Mean (mm)	SD
Face Length	USAF	120.3	6.1	106.3	6.1
	NIOSH	122.7	7.1	113.4	6.1
Face Width	USAF	142.3	5.2	129.0	5.8
	NIOSH	143.5	6.9	135.0	6.5
Lip Length	USAF	52.3	3.8	43.8	4.2
	NIOSH	51.1	4.2	48.0	4.0

A 2 (gender) x 2 (survey) MANOVA was performed to examine whether the bivariate distribution of face length and face width differ by gender and survey. Results of the MANOVA showed that gender was a significant factor, $F(2, 8342) = 5313.54$, $p < .0001$, indicating that males generally have greater face length and face width than females. Survey was also a significant factor, $F(2, 8342) = 758.98$,

p<.0001, indicating that the two anthropometric surveys were different in the combination of face length and face width. The gender-survey interaction was also significant, F (2, 8342) = 244.62, p<.0001.

Because of the significant gender-survey interactive effect, Scheffé's test was conducted to examine the effect of survey in the male and female samples, respectively. First, Scheffé's test showed that male subjects in the NIOSH survey had greater face length than subjects in the USAF survey. The difference between the male subjects in the NIOSH survey and the USAF survey (2.4 mm) is of practical importance (Table IV).

Second, Scheffé's test showed that female subjects in the NIOSH survey had greater face length than female subjects in the USAF survey. The difference between the NIOSH and USAF survey (7.2 mm) was interpreted as indicating practical importance (Table IV).

Third, Scheffé's test showed that male subjects in the NIOSH survey had greater face width than male subjects in the USAF survey. The difference between the NIOSH and the USAF surveys (1.2 mm) was interpreted as indicating no practical importance (Table IV).

Fourth, Scheffé's test also showed that female subjects in the NIOSH survey had greater face width than female subjects in the USAF survey. The difference in face width between female subjects in NIOSH and the USAF surveys (6.1 mm) was interpreted as indicating practical importance (Table IV).

Bivariate Distribution of Face Length and Lip Length

Table IV presents summary statistics of face length and lip length in the NIOSH and USAF surveys. As the table indicates, the mean differences in the bivariate distribution of face length and lip length were greater for women than for men. Because the mean difference in face length was presented previously, this face dimension is not presented here. The mean difference in lip length between the NIOSH and USAF was 1.2 mm for men whereas the difference was 4.2 mm for women.

A 2 (gender) x 2 (survey) MANOVA showed that gender was a significant factor, F (2, 8344) = 4798.67, $p < .0001$. Survey was also a significant factor, F (2, 8344) = 628.93, $p < .0001$. The gender-survey interaction was significant, F (2, 8344) = 542.79, $p < .0001$.

Because of the significant gender/survey interactive effect, Scheffé's test was conducted to examine the effect of survey in the male and female samples, respectively. First, Scheffé's test showed that male subjects in the NIOSH survey had smaller lip length than subjects in the USAF survey. The difference between the male subjects in the NIOSH survey and the USAF survey (1.2 mm) was interpreted as indicating no practical importance (Table IV).

Second, Scheffé's test showed that female subjects in the NIOSH survey had greater lip length than female subjects in the USAF survey. The difference between the NIOSH and USAF survey (4.2 mm) was of practical importance (Table IV).

Effects of Age and Race/Ethnicity on Face Dimensions

Table V presents summary statistics for face length, face width and lip length by age group and racial/ethnic group in the NIOSH survey. Additional MANOVA (2 genders x 3 age groups x 4 racial/ethnic groups) was performed to examine the effects of age and race/ethnicity on key face dimensions in the NIOSH survey. The MANOVA showed that gender was a significant factor, F (3, 3996) = 462.47, $p < .0001$. Age was statistically significant, F (6, 7992) = 30.05, $p < .0001$. Subsequent univariate analysis indicated that the workers of ages 45-65 had greater face length, face width and lip length than workers of ages 30-44 who in turn had greater face dimensions than workers of ages 18-29 ($p < .01$). Most of these differences were of practical importance. Race was also a statistically significant factor, F (9, 9725) = 97.04, $p < .0001$. Subsequent univariate analysis indicated that African American men and women had greater face length, face width and lip length than one or more of the other three groups ($p < .01$). Specific differences between any particular groups can be found in Table V. Means with different superscripts (A, B, C or D) were significantly different. For example, the mean face length of 124.5 for male ages 45-66 has a superscript "A" and the mean face length of 123.2 for male ages 30-40 has a superscript "B". These two means have different superscripts and are significantly different.

Table V. Summary Statistics for Face Length, Face Width and Lip Length by Age Group and Racial/Ethnic Group in the NIOSH Survey

Face Dimensions	Age Groups	Male			Female		
		n	Mean † (mm)	SD	n	Mean † (mm)	SD
Face Length	45-66	905	124.5 ^{A}	7.4	655	115.0 ^{A}	6.6
	30-44	1095	123.2 ^{B}	6.9	508	114.2 ^{B}	6.3
	18-29	552	120.9 ^{C}	6.7	309	112.9 ^{C}	6.2
Face Width	45-66	905	145.4 ^{A}	6.6	654	136.9 ^{A}	6.3
	30-44	1094	143.2 ^{B}	6.6	508	136.2 ^{A}	6.8
	18-29	552	142.5 ^{C}	7.3	309	135.1 ^{B}	6.4
Lip Length	45-66	905	52.8 ^{A}	4.3	655	50.4 ^{A}	4.4
	30-44	1094	51.5 ^{B}	4.1	508	49.2 ^{B}	4.3
	18-29	552	49.9 ^{C}	4.0	309	46.7 ^{C}	3.8
Face Dimensions	Race	Male			Female		
		n	Mean † (mm)	SD	n	Mean † (mm)	SD
Face Length	Caucasian	1372	122.6 ^{B}	6.9	525	113.1 ^{C}	5.8
	African Am.	636	125.4 ^{A}	7.3	601	116.5 ^{A}	6.4
	Hispanics	413	122.6 ^{B}	6.9	127	114.5 ^{B}	6.3
	Others	131	120.7 ^{C}	7.3	220	110.8 ^{D}	6.4
Face Width	Caucasian	1371	142.9 ^{B}	6.7	525	133.8 ^{B}	6.2
	African Am.	636	144.7 ^{A}	7.3	600	137.6 ^{A}	6.2
	Hispanics	413	145.7 ^{A}	6.9	127	137.7 ^{A}	6.4
	Others	131	144.7 ^{A}	7.1	220	137.8 ^{A}	6.4
Lip Length	Caucasian	1372	50.7 ^{B}	4.0	525	47.1 ^{C}	3.5
	African Am.	636	54.3 ^{A}	3.9	601	51.9 ^{A}	3.9
	Hispanics	413	51.1 ^{B}	3.8	127	49.1 ^{B}	3.9
	Others	131	50.5 ^{B}	4.5	220	46.8 ^{C}	4.2

† Means with different letter (A, B, C or D) within each dimension by age (or race) group are significantly different.

Evaluating the Representativeness of the LANL Full-facepiece Panel

As indicated in the above analyses, the two anthropometric surveys were different in the bivariate distribution of face length and face width and the bivariate distribution of face length and lip length. However, it is not clear how seriously these differences would influence the ability of the LANL panels to provide anthropometric references for respirator fit testing. This issue is examined in this section. A bivariate approach was employed to analyze the distributions of face length and face width. Table VI presents the results of the analysis involving the male and female populations of the NIOSH survey. The shaded area represents the subjects whom the LANL full-facepiece panel would have included and the un-shaded area represents the subjects whom the LANL full-facepiece panel would have excluded. The table indicates that the LANL panel would have excluded 19.3 percent of the male population and 8.4 percent of the female population, or 15.3 percent of the total population. The male and female civilian subjects have larger face length and face width than the USAF male and female subjects, respectively. Therefore the LANL full-facepiece panel should be modified to more accurately represent today's U.S. civilian population.

Table VI. Fitting the Weighted NIOSH Data into the LANL Full-Facepiece Panel

		Face Width (mm)					
		117.5	126.5	135.5	144.5	153.5	
Face Length (mm)	133.5	0.0% M 0.0% F 0.0% T	0.0% M 0.0% F 0.0%T	0.4% M 0.0% F 0.3% T	1.6% M 0.0% F 1.0% T	3.2% M 0.0% F 2.0% T	0.9% M 0.0% F 0.6% T
	123.5	0.0% M 0.0% F 0.0% T	0.1% M 0.2% F 0.1%T	3.2% M 1.1% F 2.4% T	16.8% M 3.1% F 11.8% T	15.7% M 0.8% F 10.2% T	3.8% M 0.3% F 2.5% T
	113.5	0.0% M 0.0% F 0.0% T	0.3% M 2.6% F 1.1% T	6.0% M 18.8% F 10.6% T	19.7% M 15.9% F 18.3% T	15.7% M 3.5% F 11.2% T	2.9% M 0.5% F 2.0% T
	103.5	0.0% M 0.0% F 0.0% T	0.0% M 5.7% F 2.1% T	2.4% M 23.1% F 10..% T	4.4% M 17.4% F 9.2% T	2.3% M 2.3% F 2.3% T	0.4% M 0.0% F 0.3% T
	93.5	0.0% M 0.1% F 0.1% T	0.1% M 1.0% F 0.4% T	0.0% M 2.4% F 0.9% T	0.0% M 0.9% F 0.4% T	0.0% M 0.3% F 0.1% T	0.1% M 0.0% F 0.0% T

Gender	Shaded Area		Un-Shaded Area		All	
	N	%	N	%	N	%
Male	2055	80.8	488	19.2	2543	100
Female	1331	91.6	123	8.4	1454	100
Total	3386	84.7	611	15.3	3997	100

Shaded area corresponds to the area accepted by the LANL full-facepiece panel; Un-shaded area represents the proportion of the survey subjects that is excluded by the LANL full-facepiece panel.

Evaluating the Representativeness of the LANL Half-facepiece Panel

Face length and lip length are the two face dimensions involved in the development of the LANL half-facepiece test panel. The inclusion of lip length as a key dimension is due to the fact that a half-facepiece respirator must be wider than the lips in order to seal properly. Table VII shows that fitting the NIOSH data into the LANL half-facepiece panel resulted in the exclusion of 7.6 percent of the male subjects and 1.1 percent of the female subjects, or 5.2 percent of the total population. This exclusion rate is reasonable. However, it should be noted that the bivariate distribution of face length and lip length was different between the USAF and NIOSH surveys. An adjustment of the LANL half-facepiece panel, especially the face length component, will significantly improve its sizing references for the current U.S. workers.

DISCUSSION

The present investigation showed that the LANL full-facepiece panel is not representative of the current U.S. civilian population, because the USAF anthropometric survey, on which it is based, differs from the current civilian population in the bivariate distribution of face length and face width.

Table VII. Fitting the Weighted NIOSH Data into the LANL Half-Facepiece Panel

		Lip Length (mm)			
		34.5	43.5	52.5	61.5
Face Length (mm)	133.5	0.0% M 0.0% F 0.0% T	3.2% M 0.0% F 2.1% T	2.9% M 0.0% F 1.8% T	0.1% M 0.0% F 0.1% T
	123.5	0.7% M 0.3% F 0.5% T	23.0% M 3.4% F 15.8% T	15.7% M 1.8% F 10.6% T	0.3% M 0.0% F 0.2% T
	113.5	1.8% M 4.6% F 2.8% T	28.4% M 30.7% F 29.2% T	13.9% M 5.9% F 11.0% T	0.3% M 0.0% F 0.2% T
	103.5	0.6% M 7.7% F 3.2% T	6.2% M 36.5% F 17.3% T	2.8% M 4.3% F 3.4% T	0.0% M 0.0% F 0.0% T
	93.5	0.1% M 0.9% F 0.4% T	0.0% M 3.2% F 1.2% T	0.1% M 0.6% F 0.2% T	0.0% M 0.0% F 0.0% T

Gender	Shaded Area		Un-Shaded Area		All	
	N	%	N	%	N	%
Male	2350	92.4	193	7.6	2552	100
Female	1438	98.9	16	1.1	1454	100
Total	3788	94.8	209	5.2	3997	100

Shaded area corresponds to the area accepted by the LANL half-facepiece panel; Un-shaded area represents the proportion of the survey subjects that is excluded by the LANL half-facepiece panel.

The failure of the LANL test panels to accommodate the U.S. civilian population may be partially attributed to the fact that the military population is a subset of the total population. Differences between the two populations were of concern in the original panel development but were not adequately addressed. Hack and his associates (1973) compared male face dimensions taken by USAF (Kennedy, 1986) and LANL (Hack *et al.*, 1973) and found close agreement between the two surveys. However, the LANL survey included only 200 men and 40% of them were Hispanic Americans. The small sample size, absence of female subjects, and a disproportional representation of Hispanic Americans may have confounded the military-civilian differences. Stein (1978) surveyed sixteen head and face characteristics of mine rescue team personnel and found little practical differences between his survey and the LANL survey, the USAF survey and the Australian survey (Hughes and Lomaev, 1972). However, his sample size was only 47 and all of them were Caucasian men. The present study indicated that the LANL full-facepiece panel would excluded 15.3 percent of the NIOSH sample. Because the NIOSH survey is a large-scale civilian survey, it is reasonable to assume that this survey is more representative of the US civilian population than either the LANL survey or Stein's survey. The present investigation shows that the American civilian workers have a greater bivariate distribution of face length and face width than the LANL full-facepiece panel can accommodate.

In addition, demographic changes in age or race had significant influences on the bivariate distribution of face length and face width. As shown in this study, age and race/ethnicity influenced face length, face width and lip length. Previous studies also showed that age is an important influence on body and craniofacial dimensions of a given population (Stoudt *et al.*, 1965; Miall *et al.* 1967; Isreal, 1973).

Likewise, earlier studies showed that race and ethnicity influenced anthropometry (Pheasant, 1996). It is clear that the age and race distribution of the USAF were different from the current U.S. civilian population. For example, African American men and women represent 11.6 and 12.9 percent, respectively, of the total U.S. civilian population. In contrast, the USAF sample consisted of 97.8% Caucasian men and 91.4% Caucasian women. It seems reasonable to conclude that the bivariate distribution of face length and face width is subject to the influence of these demographic differences.

The NIOSH survey clearly showed that African Americans have greater lip length than non-African Americans. In addition, females in the NIOSH survey appeared to have a greater lip length than the females in the USAF survey. Therefore, the LANL panels should be modified to more closely match the current U.S. civilian population.

The NIOSH survey represents the first large-scale civilian survey of face dimensions specifically for sizing and designing respirators in the United States. Currently, NIOSH is undertaking further research in the establishment of new respirator fit test panels representative of the current U.S. civilian workers.

CONCLUSIONS

The LANL respirator panels, which were based on the 1967-68 USAF anthropometric survey, have served the U.S. workforce for more than 30 years. However, the demographic changes over these years and military-civilian differences in face anthropometry necessitate a modification of the panels. The current investigation showed that the LANL full-face-piece panel excluded more than 15 percent of the current U.S. population. In addition, subjects in the 2003 NIOSH survey had greater key face dimensions (face length and face width) than the subjects in the 1967-68 USAF survey. In contrast, the recent NIOSH survey on face anthropometry of respirator users is more representative of the age and racial/ethnic distributions of the current civilian population. It is recommended that the LANL panels be revised so that they may continue to provide valid anthropometric references in respirator fit testing for the current U.S. civilian population.

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