Encumbered and Traditional Anthropometry of Law Enforcement Officers for Vehicle Workspace and Protective Equipment Design

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Objectives: This study investigated anthropometric changes of national law enforcement officers (LEOs) in 46 years, compared the differences between LEO data and civilian anthropometry, and identified the magnitude of differences in dimensions measured with gear versus semi-nude measurements.

Background: The best available 46-year-old anthropometric dataset of LEOs has largely become outdated due to demographic changes. Additionally, anthropometric data of female LEOs and LEO measurements with gear are lacking.

Method: Thirty-four traditional body dimensions and 15 with gear measurements of 756 male and 218 female LEOs were collected through a stratified national survey using a data collection trailer that traveled across the U.S. and the data were compared to the LEO anthropometric data from 1975 and existing civilian anthropometric databases.

Results: LEO body size and shape have evolved over the past 46 years - an increase of 12.2 kg in body weight, 90 mm in chest circumference, and 120 mm in waist circumference for men. No previous data was available for comparison for females. Compared to civilians, both male and female LEOs have a larger upper body build. LEO gear added 91 mm in waist breadth for men and 120 mm for women, and 11 kg in weight for men and 9 kg for women.

Conclusion: The study reveals that equipment design based on the existing civilian datasets or 46-year-old LEO dataset would not accommodate the current LEO population. The new data fill this gap. **Application:** The differences reported above are important for LEO body gear, vehicle console, and vehicle ingress/egress design.

Keywords: Police, body size, women, protective gear, vehicle, egress

INTRODUCTION

The accommodation of worker anthropometric variability in the workplace is key to safe and efficient completion of work tasks. For many law enforcement officers (LEOs), vehicles are the workplace where they spend significant portions of their workday. Design improvements of vehicle console space, vehicle ingress/egress, and LEO body-worn equipment can result in reduced LEO fatigue, pain, or injury (McKinnon et al., 2011). Whatever improvements might be made hinge on the availability of anthropometric data describing the size of LEOs (Molenbroek et al., 2009). Recognizing the importance of anthropometric data as early as the 1970s, the Law Enforcement Standards Laboratory of the National Bureau of Standards commissioned an anthropometric survey of male LEOs (Martin et al., 1975). The U.S. population has changed in body size and shape since 1975, and it is likely LEO size and shape have changed as well (Hsiao et al., 2021). In addition, LEOs now carry considerably more equipment than they did 46 years ago and police vehicles are more fully equipped with an array of electronic and safety gear, all of which take up valuable space within the vehicle. Moreover, no systematic LEO anthropometric dimensions measured over clothing and with gear (Figure 1),

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HUMAN FACTORS
2024, Vol. 66(1) 17–39
DOI:10.1177/00187208211064371

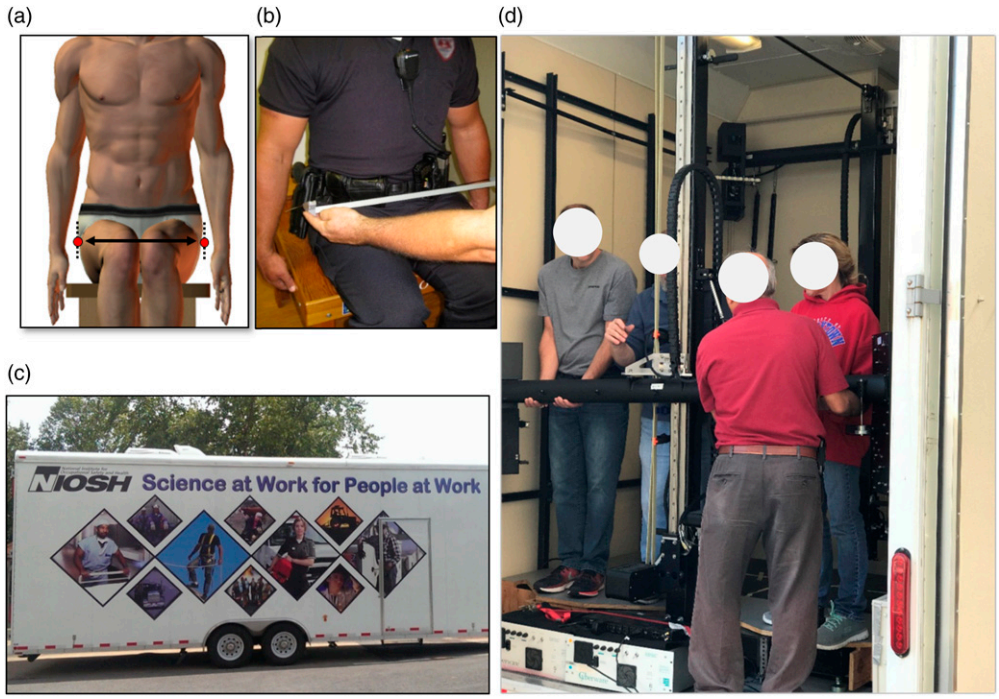

Figure 1. An example of LEO traditional semi-nude measurements (1a; Hotzman et al., 2011) and encumbered measurements (1b; Hsiao et al., 2021) sampled across the U.S., using a trailer (1c) which was equipped with a series of 3-dimensional scanners, such as a Cyberware WBX 3-D whole body scanner (1d).

known as encumbered anthropometry (Garlie & Choi, 2014; Hsiao et al., 2021), are available to address the LEO workspace challenges. Finally, the earlier study included only male officers; there were no anthropometric data of female LEOs.

An awareness of these changes and the lack of female data and encumbered data led the National Institute for Occupational Safety and Health (NIOSH) to conduct a pilot study of 74 local LEOs in 2014 which found noticeable differences between the 1975 sample and the pilot study of LEOs (Hsiao et al., 2021), especially in body weight, chest circumference, waist circumference, and shoulder breadth. As a result, NIOSH conducted a full study of LEO anthropometry in 2018–2020, sampling LEO personnel across the U.S., using a mobile data collection trailer (Figure 1).

OBJECTIVES

The objectives of this study were to (1) develop an updated U.S. LEO anthropometry database, (2) determine changes in LEO anthropometry over the past 46 years, (3) identify the magnitude of difference in dimensions measured over clothing and with gear as compared to semi-nude measurements, and (4) verify the anthropometric differences between LEOs and civilians. The information is critical for LEO vehicle workspace design and modeling (Hsiao et al., 2015), vehicle ingress/egress configurations, and personal protective equipment (PPE) design (such as body armor sizing).

METHODS

Study Design

There were three major components of the full study—anthropometric data, 3D body surface scanning, and LEO equipment assessment. The anthropometric data include measurements of traditional semi-nude dimensions and encumbered dimensions measured over clothing and with gear. The 3D scanning includes

3-dimensional scans of the head, right hand, right foot, and whole body. The assessment data include questions about the officers' cruiser, workday, and equipment used on the job. This paper focuses on the "anthropometric data" component.

Body Dimension Selection

Body dimensions were selected according to their utility for vehicle interior design, seat and seatbelt configuration, and body equipment sizing, as well as for concurrence with the Martin et al. study (1975) so that body size changes over time could be documented. Thirty-four traditional dimensions met these criteria. Additionally, 15 dimensions were measured with officers wearing their uniforms and body-borne equipment in order to document how much space is taken up by an officer's clothing and equipment (see Appendix 1).

Sampling Goals

The research was initiated in 2012. At the time, there were 714,000 LEOs in the U.S. with a distribution of 13% females and 87% males (U.S. Census Bureau, 2012). Among the LEOs, 70% were White, 12.1% Black, and 17.9% Hispanic and others. They were about evenly distributed among three age groups: 16–34, 35–44, and ≥45. This study used a stratified sampling plan (gender × race/ethnicity × age combinations) to collect anthropometric data in the U.S. Since "Black" and "Hispanic and others" groups are relatively few in number, it is impractical to divide them into different age groups. A total of 10 cells (2 gender × 3 age groups for White and 2 gender groups for Black and Hispanic/Other each) were proposed for the study to represent anthropometric differences among U.S. LEOs. The needed within-cell sample size was calculated using the following equation: $|\overline{X} - \upsilon| = \frac{\sigma * \delta}{\sqrt{n}}$, where $\overline{X} - \upsilon$ is within-cell accuracy, $\overline{X}$ is the sample mean of the subgroup, υ is the true mean of the subgroup, σ is the *SD* of the subgroup, δ is the eccentricity: 1.96 for 5% two-sided probability, and n is the sample size (Hsiao et al., 2014).

Stature is the most commonly used dimension in anthropometric studies for workplace and equipment design applications. Based on the *SD* of stature of 70 mm for men from our 2014 pilot study (Hsiao et al., 2021) and the desired cell accuracy of 15 mm for this study, the estimated sample size was 84. Thus, 100 participants per cell for a total of 1000 participants would be adequate. While 13% of LEOs were female in 2012, this study proposed to recruit 300 female LEOs in that 130 females may provide insufficient variation in the non-White ethnic groups. Table 1 summarizes the proposed number of participants across four regions in the U.S., taking into account the geographic density of population distributions calculated from U.S. Census 2010 (U.S. Census Bureau, 2012).

DATA COLLECTION

Prior to data collection, the team consisting of 6 experienced anthropometry measuring professionals was trained to exacting standards, using dimension descriptions and the allowable intra- and inter-observer errors most recently updated for the 2010 U.S. Marine Corps anthropometric survey (Hotzman et al., 2011) as the benchmark.

Sample Acquisition

A logistics team contacted possible sites in each of the four U.S. Census regions based on their size and potential ability to identify officers that met the demographic goals. Once a police department agreed to participate, the data collection team began to coordinate with the site on participant recruitment, facility needs, acceptable dates, and working hours. Each site received electronic flyers and an online scheduling application was used for the officers' convenience. LEOs from 12 facilities participated in the study.

Data Collection Procedures

As indicated in the Study Design subsection, this paper focuses on the anthropometric data (semi-nude and encumbered anthropometry) component of a full study. This data collection procedures subsection, however, documents all steps of the full study for its completeness. An anthropometer, a beam caliper (GPM, Switzerland), two tape measures (Lufkin, U.S.), an

Table 1. Sampling goals by racial/ethnic group, sex, age, and regions.

	White (*N* = 700)						Black (*N* = 121)		Hispanic/ Other (*N* = 179)		
	Male			Female							
	16–34	35–44	≥45	16–34	35–44	≥45	Male	Female	Male	Female	Total
Pacific West	36	34	35	15	15	15	7	3	54	22	236
North Central	44	43	42	18	18	18	16	7	16	7	229
North East	39	38	37	17	17	17	23	9	26	12	235
South	49	47	46	20	20	20	39	17	29	13	300
Total	490			210			85	36	125	54	1000

electronic scale (MedWeigh, U.S.), and a dynamometer for measuring grip strength (Smedley, U.S.) were used to obtain the measurement data. Upon arrival at the measuring site, each officer was given a consent form to read and then asked if he or she had any questions. Participants who agreed to take part in the survey signed the consent form and were asked to provide demographic information. They then donned their full uniform, body armor, duty belt, and other gear if they did not already have it on.

Officers began with the first measuring station where measurements over gear were taken. Fifteen measurements were taken through palpation and visual inspection. At the conclusion of the gear measurements, officers changed into scan wear, which included Spandex shorts for men. Women used Spandex shorts and a sports bra. Wig caps were used to compress participants' hair which minimized the effect of hair on scan results. At the second measuring station, body landmarks were placed with eyeliner pencil or adhesive dots and the semi-nude measurements were taken. As the body measurements were taken and entered into the laptop computer, they were subjected to an instant error check, using a combination of outlier identification and regression techniques. Potential errors were signaled to the recorder who could then ask the measurer to retake that measurement. Paper data sheets were also used as the backup "database".

After completing the two anthropometry stations, officers were provided a robe to wear while they moved to a mobile anthropometry laboratory. Each participant was scanned five times with a set of 3D scanners. Individual scans were made of the head, right hand, right foot and whole body; whole body scans were taken standing and seated. The following scanners were used: Cyberware WBX 3-D whole body scanner and head-and-face color 3D scanner (Cyberware Inc, Monterey, CA), hand scanner by Visimage Systems Inc (Markham, ON, Canada), and YETI foot scanner by Vorum (Vancouver, BC, Canada). Participants then returned to the first measuring station and completed an assessment on a tablet computer of questions related to their uniform and patrol car. When finished with the entire process, the officers donned their duty uniform or street clothes, and were compensated for their time (63 minutes) and released. Female officers were landmarked, measured, and scanned by female measurers.

This paper describes the anthropometric data. LEOs' assessment regarding their uniform and patrol car as well as the collected 3D scans and their applications will be reported in other papers. This research complied with the National Institute for Occupational Safety and Health (NIOSH) Code of Ethics and was approved by the Institutional Review Board (IRB) at NIOSH (#14-DSR-02XP), and the U. S. Office of Management and Budget (OMB #0920-1232).

Data Editing

As noted in the Data Collection Procedures section, we used an on-site data editing application to minimize errors during the data collection stage. When data collection was complete, we undertook another round of editing of the

Table 2. Sampling outcomes.

	White Goal: N = 700; Actual: N = 685						Black Goal: N = 121; Actual: N = 124		Hispanic/Other Goal: N = 179; Actual: N = 165		
	Males			Females			Males	Females	Males	Females	Total
		18–34	35–44	≥45	18–34	35–44	≥45	≥18	≥18	≥18	≥18
Goal (A)	168	162	160	70	70	70	85	36	125	54	1000
Actual (B)	188	183	172	52	62	28	93	31	120	45	974
B minus A	+20	+21	+12	(18)	(8)	(42)	+8	(5)	(5)	(9)	(26)
Total Actual, men	543						93		120		756
Actual, women				142				31		45	218

+: indicates an oversample; ( ): indicates a short of sample.

complete dataset, using Cook's Distance, which is a measure of the influence of a given data point in a least-squares regression analysis (Cook, 1977). We identified those values with higher Cook's Distance (e.g., cases where too few or too many digits were entered or when a data value was entered for an incorrect dimension). Since we had paper data sheets as backup to the digital data, we pulled the data sheet to see if an entry error was made. If a correct value could not be determined, the flagged value was marked as "missing." Finally, 3D scans along with the Anthroscan software (Human Solutions Inc) were used to verify a few "suspectable" data measurements. There were nine missing data measurements which were impractical to recover. For instance, there was one missing Stature measurement which is associated with the styled updo hair of a female officer. The data sheet noted that it was infeasible to measure and the scan image confirmed that.

DATA ANALYSIS

Nine hundred and seventy-four (974) law enforcement officers across the U.S. comprised the sample for this study (Table 2). Of the participants, 756 were men which met our goal of 700. We had 218 women which were 82 participants short of the goal of 300. Female LEOs represented 13% of the LEO population in 2012 (the time the research was planned) and 17.6% of LEOs in 2020 (the time data collection was completed). Therefore, 130 to 176 females would be needed in this study. With 218 women and through appropriate weighting procedures, we can adequately address vehicle workspace and PPE issues unique to female LEOs.

Statistical Weighting

It is rare that sample acquisition exactly matches a sampling plan. A statistical weighting technique can be used to address the gap by comparing the actual sample to the target sample for each individual measured value to represent the population of interest (Hsiao et al., 2021). Since LEO demographics changed slightly between the time the sampling plan was originally created and the time data collection was finished, the weighting process also gives us the opportunity to use more recent population demographics to make the resulting summary statistics as up to date as possible.

To calculate the weights, we used racial/ethnic data from the Bureau of Labor Statistics (BLS), updated for 2019, and broke it down into the same categories we had used in our sampling plan. We used the labor category "police and sheriff's patrol officers" as the population which was 716,000 (Bureau of Labor Statistics, 2020). Our sampling plan included three broad age groups, equivalent in size, to capture all the age-related variability based on population distributions. We used those age groups along with the BLS racial/

Table 3. Law enforcement officers sample calculated weights.

	Males			Females		
Age Group	White	Black	Hispanic/Other	White	Black	Hispanic/Other
18–34	0.9527	0.8785	0.9676	0.9804	0.6333	0.6849
35–44	0.9322	0.8785	1.4515	0.8064	0.8444	1.2556
≥45	0.9908	0.7751	1.8018	1.7241	0.7599	1.3698

ethnic categories to calculate the weights, computing males and females separately (Table 3). The weight for each racial/ethnic by age cell for each gender can be expressed as

$$\frac{\left[\frac{N_{1,1}}{\left(N_{1,1}+N_{1,2}+\ldots+N_{i,j}\right)}\right]}{\left[\frac{n_{1,1}}{\left(n_{1,1}+n_{1,2}+\ldots+n_{i,j}\right)}\right]}$$

where N is the count from the age/race cell in the BLS data,

n is the count from the age/race cell in the present study, i is the subscript for the last age group, and j is the subscript for the last racial group.

RESULTS

Weighted Summary Statistics

With statistical weights applied, a series of summary statistics were calculated for each dimension (Table 4), which includes traditional (semi-nude) measurements and encumbered measurements. The visual descriptions of the measurements are presented in Appendix 1.

Current Law Enforcement Officers (LEO) Data Compared with 1975 Law Enforcement Officers Data

Table 5 shows the results of t-test comparisons of means between the current and Martin et al. (1975) studies for semi-nude measurements for men. The Martin et al. dataset of 1975 contained only semi-nude measurements and all participants were men. Ten of the 16 dimensions were different at the two-tail $\alpha = 0.05$ statistical significance level for 16 paired multiple comparisons.

The results show that most of the comparably measured dimensions are larger in the current study sample. The largest differences are found in Waist Circumference, Chest Circumference, and Chest Breadth. Body weight is also considerably larger in this study. Head Length and Head Circumference are larger, although the difference is only a few millimeters; the differences are larger than "allowable measurement errors" and thus are genuine (Hotzman et al., 2011). Head Breadth, Hand Length, Hand Breadth, Front Waist Length, Stature, and Thumbtip Reach are not different between the two anthropometric surveys.

Encumbered Measurements as Compared to Semi-Nude Measurements

The summary statistics for anthropometry with gear were included in Table 4. The definitions of seven of the 15 encumbered dimensions are similar enough to those of the traditional semi-nude measurements and thus comparisons can be made. Table 6 shows the differences in means between the dimensions measured over gear and without gear for each gender.

The greatest differences occur at the hip and waist, near the area where the duty belt is worn. For males, the Hip Breadth (sitting) is most affected with a 105-mm difference, while the 120 mm difference between the encumbered and unencumbered Waist Breadth is the greatest difference for the females. Table 6 also includes the differences found at various percentiles. For some dimensions, for example Chest Depth in the males, the 5th percentile difference is only 16 mm, which is not especially large. But at the other end of the distribution the 95th percentile difference is 84 mm, which could easily have

Table 4. Summary statistics of the measured dimensions (weighted) (weight and grip strength in kg, all other values in mm).

		Males				Females			
Dimension		N*	Mean	Std Dev	Std Error	N*	Mean	Std Dev	Std Error
Semi-nude measurement	Bideltoid breadth, sitting	756	514	33	1.2	218	452	28	1.9
	Buttock height	756	914	51	1.8	218	859	44	3.0
	Buttock–knee length	756	631	34	1.2	218	600	31	2.1
	Buttock–popliteal length	756	514	30	1.1	218	493	27	1.8
	Chest breadth	756	373	36	1.3	218	322	31	2.1
	Chest circumference	756	1112	101	3.7	218	995	104	7.0
	Chest depth	756	281	30	1.1	218	269	36	2.5
	Crotch height	756	841	51	1.9	218	794	44	3.0
	Elbow rest height, sitting	756	254	29	1.1	218	248	27	1.8
	Eye height, sitting	756	809	34	1.2	218	761	31	2.1
	Foot breadth, horizontal	756	105	6	0.2	218	96	5	0.3
	Foot length	756	269	14	0.5	218	244	12	0.8
	Grip strength, sitting (kg)	756	49.4	9.9	0.36	218	32.1	6.2	0.42
	Hand breadth	756	90	4.7	0.2	218	80	4.0	0.3
	Hand length	756	194	9.9	0.4	218	178	9	0.6
	Head arc length	756	359	15	0.5	218	339	14	1.0
	Head breadth	756	155	6	0.2	217	146	5	0.3
	Head circumference	756	579	16	0.6	212	554	16	1.1
	Head length	756	201	7	0.3	213	188	7	0.5
	Hip breadth, sitting	756	401	32	1.2	218	419	41	2.8
	Hip circumference	756	1068	86	3.1	218	1055	104	7.1
	Knee height, sitting	756	566	30	1.1	218	522	26	1.8
	Nuchal height, sitting	756	785	35	1.3	218	732	33	2.2
	Popliteal height	756	432	27	1.0	218	393	24	1.6
	Sitting height	756	930	35	1.3	218	875	32	2.1
	Stature	756	1776	71	2.6	217	1651	64	4.3
	Thigh circumference	756	653	57	2.1	218	644	63	4.2
	Thumbtip reach	756	830	48	1.8	218	759	41	2.8
	Waist breadth, sitting	756	360	40	1.5	218	328	43	2.9
	Waist breadth height, sitting	756	223	19	0.7	218	233	19	1.3
	Waist circumference (Omp.)	756	1026	129	4.7	218	914	131	8.9
	Waist front length, sitting	756	409	31	1.1	218	381	27	1.8
	Waist height (Omphalocele)	756	1058	57	2.1	218	985	51	3.4
	Weight (kg)	756	95.4	17.3	0.63	218	74.9	14.1	0.95

(Continued)

Table 4. (Continued)

Dimension		Males				Females			
		N*	Mean	Std Dev	Std Error	N*	Mean	Std Dev	Std Error
Measurement with gear	Abdom. exten. depth, sitting	756	351	46	1.7	218	318	40	2.7
	Acromion–trochanter surface length, sitting	755	837	53	1.9	218	790	47	3.2
	Bideltoid breadth, sitting	756	543	37	1.3	218	484	34	2.3
	Bi-trochanter surface length, sitting	756	719	63	2.3	218	672	62	4.2
	Boot breadth	756	114	6	0.2	218	105	5	0.3
	Boot length	756	309	14	0.5	218	278	12	0.8
	Buttock–boot tip length	756	795	48	1.7	218	753	51	3.5
	Chest breadth	756	385	32	1.2	218	347	26	1.7
	Chest depth	756	326	32	1.2	218	309	30	2.0
	Hip breadth	756	506	37	1.3	218	489	37	2.5
	Shoulder-grip length	756	803	41	1.5	218	741	38	2.6
	Stature with boots	756	1804	72	2.6	217	1681	64	4.3
	Thigh clearance	756	197	17	0.6	218	181	17	1.2
	Waist breadth	756	451	50	1.8	218	449	50	3.4
	Weight, (kg), gear	756	106.3	18	0.65	218	84.2	14	0.94

*The *N* values are actual participant number. The means, standard deviations, and standard errors of means are weighted.

Table 5. Summary statistics of law enforcement officers in this study and Martin et al. (1975): males (weight in kg, all other values in mm).

	NIOSH 2020				Martin 1975					
Dimension	N	Mean	Stand error	Stand Dev	N	Mean	Stand error	Stand Dev	N–M[a]	Allo. error
Bideltoid breadth, sitting	754	514	1.2	33	2985	495	0.5	29.4	19[b]	8
Buttock–knee length	754	631	1.2	34	2988	615	0.5	27.1	16[b]	6
Chest breadth	754	373	1.3	36	2984	346	0.5	26.4	26[b]	7
Chest circumference	754	1112	3.7	101	2990	1022	1.4	79.0	90[b]	14
Front waist length, sitting	754	409	1.1	31	2983	413	0.5	26.9	-4[c]	7
Hand breadth	754	90	0.2	5	2987	90	0.1	4.2	0[c]	2
Hand length	754	194	0.4	10	2989	194	0.2	9.1	0[c]	3
Head breadth	754	155	0.2	6	2993	155	0.1	5.7	0[c]	2
Head circumference	754	579	0.6	16	2985	575	0.3	15.8	4[b]	3
Head length	754	201	0.3	7	2992	198	0.1	7.0	3[b]	2
Knee height, sitting	754	566	1.1	30	2984	559	0.5	25.3	7[b]	2
Sitting height	754	930	1.3	35	2993	922	0.6	34.5	8[b]	6
Stature	754	1776	2.6	71	2989	1781	1.1	57.8	−5[c]	6
Thumbtip reach	754	830	1.8	48	2987	830	0.8	42.0	0[c]	20
Waist circumference, O	754	1026	4.7	129	2988	906	1.7	94.6	120[b]	12
Weight	754	95.4	0.6	17.3	2991	83.3	0.2	12.0	12.1[b]	0.3

[a]N–M: NIOSH subtracts Martin.
[b]Indicates significantly different from each other (2-tail t-test at significance level of 0.05, with $p = 0.05/16 = 0.003125$ for 16 paired NIOSH LEO - Martin comparisons; $z = 2.96$).
[c]Indicates no significant difference from each other. Allo. Error: allowable measurement error (Hotzman et al., 2011).

a significant effect in the case of a crash in which the officer came into contact with the steering wheel.

Current Law Enforcement Officers Compared with U.S. General Population - CAESAR and NHANES

There are 19 comparable dimensions between the present LEO study and the Civilian American and European Surface Anthropometry Resource (CAESAR) database (Harrison & Robinette, 2002). There are also three comparable dimensions between the current LEO study and the National Health and Nutrition Examination Survey (NHANES) (Fryar et al., 2016). For men for the current LEO study in comparison to CAESAR data of civilians, 13 of the 19 dimensions were significantly different at the two-tail $\alpha = 0.05$ statistical significance level (Table 7). The mean body weight of the LEO sample was larger than the civilian mean by 12.2 kg. Other larger and important differences include 88 mm in mean chest circumference, 25 mm in hip breadth, 36 mm in hip circumference, 73 mm in knee height sitting, 24 mm in bideltoid breadth, and 53 mm in thigh circumference. The mean values of stature, sitting height, head dimensions, and foot length of LEOs were not statistically different from the CAESAR civilian samples. For male LEOs in comparison to NHANES civilians, the mean body weight of the LEO sample was larger than the civilian mean by 6.6 kg and the LEO sample was taller by 19 mm which were significantly different at the two-tail $\alpha = 0.05$ statistical

Table 6. Dimensional increase due to LEO gear (weight in kg, all other values in mm).

Dimension	N	Mean	Standard Deviation	Percentiles				
				5	25	50	75	95
Males								
Bideltoid breadth	756	29	15.7	7	18	28	38	58
Chest breadth	756	12	17.2	−16	1	13	23	40
Chest depth	756	45	20.6	16	31	42	56	84
Hip breadth sitting	756	105	28.1	53	90	108	122	146
Stature	756	28	7.6	16	23	28	33	41
Waist breadth	756	91	52.0	12	49	88	134	172
Weight	756	10.9	2.6	6	10	11	12	15
Females								
Bideltoid breadth	218	32	14.8	7	24	29	38	61
Chest breadth	218	25	17.3	−2	13	26	36	51
Chest depth	218	41	21.5	12	27	39	55	77
Hip breadth, sitting	218	70	32.1	14	53	72	90	112
Stature	217	30	7.9	16	25	30	35	43
Waist breadth	217	120	51.3	28	86	132	159	189
Weight	218	9.2	2.09	5	8	9	11	12

significance level (Table 8). The difference in waist circumference was not significant. Considering the comparisons of LEOs with both the CAESAR and NHANES civilian datasets, LEOs on average had a larger body build but not larger waist circumference.

For women for the current LEO study compared to civilian CAESAR data, 12 of the 19 dimensions are significantly different at the two-tail $\alpha = 0.05$ statistical significance level (Table 9). The mean body weight of the LEO sample was larger than the civilian mean by 5.3 kg. Other significant and important differences include 70 mm in mean chest circumference, 33 mm in thigh circumference, 21 mm in bideltoid breadth, and 14 mm in knee height sitting. The mean values of stature, head dimensions, hip breadth, and hip circumference were not statistically different from the CAESAR civilian samples. For female LEOs in comparison to NHANES civilians, the mean body weight of the LEO sample was no different from the civilian mean (Table 8). They were taller than the civilian mean by 33 mm and smaller in waist circumference by 55 mm which were significantly different. Considering the comparisons of LEOs with both the CAESAR and NHANES civilian datasets, female LEOs on average had a larger upper body build and a smaller waist circumference than the civilian populations.

DISCUSSION

The New Anthropometric Data of Law Enforcement Officers

Women made up 5.0% of LEOs in 1980 (Cordner & Cordner, 2011) and 17.6% of LEOs in 2019 (U.S. Bureau of Labor Statistics, 2020). The anthropometry study of LEOs in 1975 (Martin et al., 1975) did not include female LEOs. The new anthropometric dataset of female LEOs from the current study has many practical implications in equipment layout within vehicle consoles, vehicle seat adjustment and arrangement, body armor configuration and sizing, and uniform design that are unique to female LEOs. We set a goal during the project planning in 2012 for 300 women LEOs to participate in this national study which is a double sampling to increase the statistical power. With 218 women participants, we have sufficient statistical power to address vehicle

Table 7. Summary statistics of the study of law enforcement officers (LEO) compared to civilians in CAESAR database (weight in kg, all other values in mm) - Males.

Dimension	Survey	N	Mean	Std Error	NIOSH–CAESAR	Allowable Error
Bideltoid breadth	NIOSH LEO (weighted)	756	514	1.2	24[a]	8
	CAESAR	1119	490	1.1		
Buttock–knee length	NIOSH LEO (weighted)	756	631	1.2	17[a]	6
	CAESAR	1119	614	1.1		
Chest circumference	NIOSH LEO (weighted)	756	1112	3.7	88[a]	14
	CAESAR	1119	1024	3.4		
Crotch height	NIOSH LEO (weighted)	756	841	1.9	44[a]	10
	CAESAR	1119	797	1.6		
Elbow rest height, sitting	NIOSH LEO (weighted)	756	254	1.1	15[a]	10
	CAESAR	1119	239	1.1		
Eye height, sitting	NIOSH LEO (weighted)	756	809	1.2	6[b]	8
	CAESAR	1119	803	1.2		
Foot length	NIOSH LEO (weighted)	756	269	0.5	2[b]	3
	CAESAR	1119	267	0.5		
Hand length	NIOSH LEO (weighted)	756	194	0.4	−8[a]	3
	CAESAR	1119	202	0.4		
Head breadth	NIOSH LEO (weighted)	756	155	0.2	0[b]	2
	CAESAR	1119	155	0.2		
Head circumference	NIOSH LEO (weighted)	756	579	0.6	2[b]	3
	CAESAR	1119	577	0.5		
Foot length	NIOSH LEO (weighted)	756	201	0.3	1[b]	3
	CAESAR	1119	200	0.3		
Hip breadth, sitting	NIOSH LEO (weighted)	756	401	1.2	25[a]	6
	CAESAR	1117	376	1.1		
Hip circumference	NIOSH LEO (weighted)	756	1068	3.1	36[a]	
	CAESAR	1119	1032	2.9		
Knee height, sitting	NIOSH LEO (weighted)	756	566	1.1	73[a]	2
	CAESAR	1114	493	0.9		
Sitting height	NIOSH LEO (weighted)	756	930	1.3	9[a]	6
	CAESAR	1119	921	1.3		
Stature	NIOSH LEO (weighted)	756	1776	2.6	9[b]	6
	CAESAR	1119	1767	2.3		
Thigh circumference	NIOSH LEO (weighted)	756	653	2.1	53[a]	6
	CAESAR	1119	600	1.9		
Thumbtip reach	NIOSH LEO (weighted)	756	830	1.8	22[a]	20
	CAESAR	1119	808	1.4		
Weight (Kg)	NIOSH LEO (weighted)	756	95.4	0.63	12.2[a]	0.3
	CAESAR	1119	83.2	0.5		

[a]Indicates significantly different from each other (2-tail t-test at significance level of 0.05, with $p = 0.05/19 = 0.0026$ for 19 paired NIOSH LEO-CAESAR comparisons with $z = 3.02$).
[b]indicates no significant difference from each other. Allowable error: allowable measurement error (Hotzman et al., 2011).

Table 8. Summary statistics of law enforcement officers compared to NHANES survey (weight in kg, others in mm).

Sex	Dimension	Survey	N	Mean	Std Error	NIOSH -NHANES	Allowable Error
Male	Stature	NHANES	5232	1757	2.1	19[a]	6
		NIOSH LEO (weighted)	756	1776	2.6		
	Weight (kg)	NHANES	5236	88.8	0.43	6.6[a]	0.3
		NIOSH LEO (weighted)	756	95.4	0.63		
	Waist circumference	NHANES	5018	1015	3.9	11[b]	3
		NIOSH LEO (weighted)	756	1026	4.7		
Female	Stature	NHANES	5547	1618	2.1	33[a]	6
		NIOSH LEO (weighted)	217	1651	4.3		
	Weight (kg)	NHANES	5425	76.4	0.42	−1.5[b]	0.3
		NIOSH LEO (weighted)	218	74.9	0.95		
	Waist circumference	NHANES	5116	969	3.8	−55[a]	3
		NIOSH LEO (weighted)	218	914	8.9		

[a]Indicates significantly different from each other (2-tail t-test at significance level of 0.05, with $p = 0.05/3 = 0.0167$ for three paired comparisons with $z = 2.395$).
[b]indicates no significant difference from each other. Allowable error: allowable measurement error (Hotzman et al., 2011).

workspace and PPE issues unique to female LEOs.

The sample distributions of race/ethnicity in the Martin et al. study were 83.7% White, 9.8% Black, and 6.4% Hispanic and other. The LEOs in 2019 in the U.S. were 68.9% White, 12.6% Black, and 18.5% Hispanic and other (U.S. Bureau of Labor Statistics, 2020). The sample distribution of age in the Martin et al. (1975) study was 75.4% age 18–34, 15.3% age 35–44, and 9.3% age ≥45. The LEOs in 2016 in the U.S. were about evenly distributed among three age groups: 16–34, 35–44, and ≥45 (U.S. Bureau of Labor Statistics, 2018). The present LEO study sample was 36% age 22–34, 34% age 35–44, and 30% age 45–56, which matches our original estimation. The Martin et al. study did not apply an age-related weighting, nor race/ethnicity weighting in their report. The current study considered age and race/ethnicity in the sampling plan and the results were very close to the sampling estimations, except for the cells of "Hispanic males age 45 and above" and "White females age 45 and above." The statistical weighting in the current study addressed the under-representation issue with these sub-groups.

Anthropometric Changes of Law Enforcement Officers over the Past 46 Years

While the changes in stature, hand dimensions, head breath, and thumbtip reach of male LEOs were not significant over the past four decades, the changes in other dimensions were significant. The 120 mm increase in mean waist circumference, 90 mm in chest circumference, 26 mm in chest breadth, 19 mm in bideltoid breadth, and 12 kg in body weight collectively show differences in LEO body size and evolution of body shape over the past 46 years. A recent study reported that patrol officers on average spent 43.22% of their time inside vehicles and 1.28% in entering and exiting vehicles (McKinnonet al., 2011). With larger body dimensions, frequent requirements for vehicle entry and exit, and time spent in vehicles among current LEOs, there are important implications with the change of LEO body dimensions over the past 46 years on vehicle console, seat, and ingress/egress configurations or retrofitting.

In addition, the larger chest, waist, and shoulder (bideltoid breadth) dimensions have an important

Table 9. Summary statistics of the study of law enforcement officers (LEO) compared to civilians in CAESAR database (weight in kg, all other values in mm) - Females.

Dimension	Survey	N	Mean	Std Error	NIOSH -CAESAR	Allowable Error
Bideltoid breadth	NIOSH LEO (weighted)	218	452	1.9	21[a]	8
	CAESAR	1261	431	1.1		
Buttock–knee length	NIOSH LEO (weighted)	218	600	2.1	12[a]	6
	CAESAR	1260	588	1.1		
Chest circumference	NIOSH LEO (weighted)	218	995	7.0	70[a]	14
	CAESAR	1261	925	3.2		
Crotch height	NIOSH LEO (weighted)	218	794	3.0	46[a]	10
	CAESAR	1260	748	1.5		
Elbow rest height, sitting	NIOSH LEO (weighted)	218	248	1.8	11[a]	10
	CAESAR	1260	237	0.8		
Eye height, sitting	NIOSH LEO (weighted)	218	761	2.1	6[b]	8
	CAESAR	1260	755	1.0		
Foot length	NIOSH LEO (weighted)	218	244	0.8	5[a]	3
	CAESAR	1261	239	0.4		
Hand length	NIOSH LEO (weighted)	218	178	0.6	−4[a]	3
	CAESAR	1260	182	0.3		
Head breadth	NIOSH LEO (weighted)	217	146	0.3	0[b]	2
	CAESAR	1260	146	0.2		
Head circumference	NIOSH LEO (weighted)	212	554	1.1	2[b]	3
	CAESAR	1260	552	0.5		
Foot length	NIOSH LEO (weighted)	213	188	0.5	−1[b]	3
	CAESAR	1260	189	0.2		
Hip breadth, sitting	NIOSH LEO (weighted)	218	419	2.8	9[b]	6
	CAESAR	1259	410	1.5		
Hip circumference	NIOSH LEO (weighted)	218	1055	7.1	−6[b]	
	CAESAR	1259	1061	4.0		
Knee height, sitting	NIOSH LEO (weighted)	218	522	1.8	14[a]	2
	CAESAR	1261	508	0.9		
Sitting height	NIOSH LEO (weighted)	218	875	2.1	11[a]	6
	CAESAR	1260	864	1.1		
Stature	NIOSH LEO (weighted)	217	1651	4.3	13[b]	6
	CAESAR	1261	1638	2.2		
Thigh circumference	NIOSH LEO (weighted)	218	644	4.2	33[a]	6
	CAESAR	1261	611	2.4		
Thumbtip reach	NIOSH LEO (weighted)	218	759	2.8	22[a]	20
	CAESAR	1261	737	1.2		
Weight (Kg)	NIOSH LEO (weighted)	218	74.9	0.95	5.3[a]	0.3
	CAESAR	1261	69.6	0.56		

[a]Indicates significantly different from each other (2-tail t-test at significance level of 0.05, with $p = 0.05/19 = 0.0026$ for 19 paired NIOSH LEO-CAESAR comparisons with $z = 3.02$).
[b]Indicates no significant difference from each other. Allowable error: allowable measurement error (Hotzman et al., 2011)

impact on sizing structure and design of body armors and uniforms (Hsiao et al., 2021). The U.S. "Selection and application guide 0101.06 to ballistic-resistant body armor" shows that each vest armor size may cover a range of 63 mm for chest width (U.S. Department of Justice, 2014). This guide contains sizing templates for body armor test samples, and the templates are purported to represent 95% of officers (man and women). Comparing the sizing templates indicates that a full-size increase is predicted when a difference of 25 mm in chest width, 51 mm in chest circumference, or 114 mm in waist circumference occurs. The 26 mm increase in chest breadth, 90 mm in chest circumference, and 120 mm in mean waist circumference found in this study mean an increase of more than one size. It may be advisable for NIJ to consider updating their body armor test sample templates using the new database for improving LEO safety. Furthermore, the common apparel and uniform sizing charts delineate a predicted size as a range of 76 mm in chest circumference for shirts and 51 mm in waist circumference for pants. The 90-mm difference in chest circumference and 120 mm difference in waist circumference indicate a two-size increase in a uniform sizing system. This is based on male clothing as no female data was collected in 1975. It would be timely to update the LEO uniform sizing structure using the new dataset. In addition, a standard sizing guide (tested during development for actual range of fit on LEOs) with tables similar to ASTM standards tables for body measurements (ASTM International, 2021) can be developed for LEOs.

Encumbered Law Enforcement Officers Anthropometry

Encumbered anthropometric data allow a quantitative assessment of the additional size and bulk added by the uniform and accompanying gear to the traditional semi-nude measurements. The information is more realistic for workspace design than traditional anthropometry alone. Only a very few anthropometry studies have included both semi-nude and encumbered conditions (Figure 1) in the data collection (Paquette et al., 1999; Garlie & Choi, 2014; Mitchell et al., 2017; Hsiao et al., 2021). This study collected seven pairs of semi-nude and encumbered anthropometric measurements. The mean values show an increase of 105 mm in Hip Breadth (sitting) for men and 70 mm for woman, 91 mm in waist breadth for men and 120 mm for women, 45 mm in chest depth for men and 41 mm for women, 29 mm in bideltoid breadth for men and 31 mm for women, and 11 kg in gear for men and 9 kg for women. The added gear not only takes up significant space in the very tight vehicle workspace, but also increases the LEO risk of biomechanical impacts associated with contacting the driving wheel, vehicle equipment, and door should a vehicle crash occurs. It also increases the biomechanical and physiological loads on a LEO's low back and entire body. These new data provide safety professionals with the most updated information for detailed LEO safety risk assessments. In addition, duty belts were ranked the highest discomfort element within patrol duties (Cardoso et al., 2017). The 105 mm increase in Hip Breadth (sitting) for men and 70 mm for women associated with duty belts would escalate the difficulty in seatbelt use and have a negative impact on LEOs in entering/exiting vehicles. A study on "vehicle as workplace" reported that the gear LEOs wore and their large body dimensions contributed to the serious problem in entering and exiting their vehicles (Molenbroek et al., 2009).

Current Law Enforcement Officerss Compared with U.S. General Population—CAESAR and NHANES

While the comparisons of male LEOs with CAESAR civilian data and NHANES data yield slightly different estimates, the data trends are consistent. The male LEO sample is larger than the civilian data in mean body weight and upper torso dimensions although the mean stature difference is small (Figure 2). Male LEOs on average have a larger body build but not larger waist circumference than the civilian population. For females, the comparisons of LEOs with CAESAR civilian data and NHANES data yield different results in mean body weight and stature. On average, female LEOs have a larger upper body build with a smaller waist circumference (Figure 2).

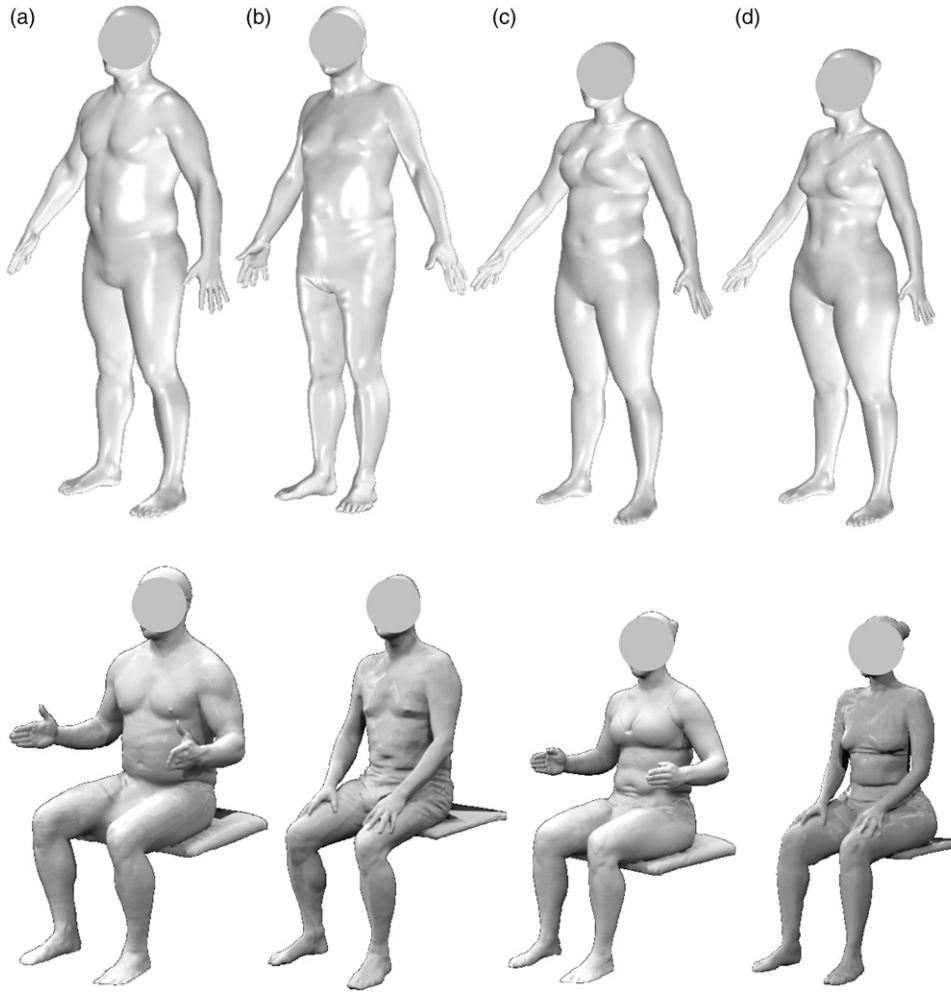

Figure 2. A "near-average" male LEO who is 1773 mm in stature and 96.3 kg in body weight (2a, standing and seated) comparing to a "near-average" male CAESAR general civilian who is 1759 mm in stature and 83.2 kg in body weight (2b, standing and seated). Also, a "near-average" female LEO who is 1658 mm in stature and 76.8 kg in body weight (2c, standing and seated) comparing to a "near-average" female CAESAR general civilian who is 1635 mm in stature and 69.2 kg in body weight (2d, standing and seated). LEOs are in general heavier than the general population and have a larger build of upper torso.

This is the first time that we have a systematic survey of female LEO anthropometry and the information is timely for improving the protection of female LEOs.

It is worth noting that the CAESAR "Waist Circumference" data was measured at the participant's self-selected waist location for specific clothing applications (e.g., jeans) rather than at the Omphalion as in other databases (Veitch, 2012). Similarly, the CAESAR Waist Front Length (surface distance between waist and the suprasternale landmark at the lowest point of the notch) was measured at the participants' preferred waist location, which is different from other databases and our study. The CAESAR Waist Circumference and Waist Front Length

thus were not included in the list of comparable dimensions for comparisons with the LEO Waist Circumference and Waist Front Length.

CONCLUSION

This study provides the first available U.S. female LEO anthropometric information. Women represented 17.6% of the LEO population in 2019 (U.S. Bureau of Labor Statistics, 2020). Yet, anthropometric information for female LEOs has been lacking. The new dataset will have practical implications for in-vehicle equipment layout, vehicle seat adjustment, armor configuration and sizing, and uniform design for the safety and well-being of female LEOs.

This study also provides the most updated anthropometry data of U.S. male LEOs. LEO body size has increased and body shape has evolved significantly over the past four decades. Comparing the semi-nude anthropometric measurements of male LEOs in the present study with the best available data of 46 years ago, there were increases of 12 kg in mean body weight, 90 mm in chest circumference, 120 mm in waist circumference, 26 mm in chest breadth, and 19 mm in shoulder breadth, while the changes in stature, hand dimensions, head breath, and thumbtip reach were minor.

The composition of U.S. LEO workforce has changed. The distributions of race/ethnicity in the Martin et al. study (1975) were 83.7% White, 9.8% Black, and 6.4% Hispanic and other. The LEOs in 2019 in the U.S. were 68.9% White, 12.6% Black, and 18.5% Hispanic and other (U.S. Bureau of Labor Statistics, 2020). The distributions of age in the Martin et al. study were 75.4% age 18-34, 15.3% age 35–44, and 9.3% age ≥45. The present LEO study sample was 36% age 22–34, 34% age 35–44, and 30% age 45–56. The current study provides the most comprehensive LEO anthropometry, considering the race/ethnicity and age compositions.

Encumbered anthropometry data allow an assessment of the additional dimensions added by the uniform and accompanying gear over the semi-nude measurements. This study collected seven pairs of measurements. The differences of 105 mm in hip breadth (sitting) for men and 120 mm in waist breadth for women are particularly notable. The additional widths are important to consider in computerized human modeling and simulations for LEO vehicle cab space configuration, ingress/egress arrangement, and other ergonomic assessments.

In comparisons to general population anthropometry (CAESAR and NHANES), LEOs in the current study on average have a larger upper body build than civilians for both men and women. For male LEOs, the differences include 88 mm in chest circumference (LEOs vs. CAESAR), 12.2 kg in weight (LEOs vs. CAESAR), and 24 mm in bideltoid breadth (LEOs vs. CAESAR). Similarly, the differences of 70 mm in mean chest circumference, 33 mm in hip circumference, 33 mm in thigh circumference, 21 mm in bideltoid breadth (LEOs vs. CAESAR), and −55 mm in waist circumference (LEOs vs. NHANES) for women demonstrated that female LEOs on average have a larger body build than female civilians. The new LEO anthropometry data provide more up to date information for LEO equipment design than CAESAR and NHANES data.

KEY POINTS

- Anthropometric data representing race/ethnicity, age, and sex distributions of current law enforcement workforce were lacking. This study filled this gap.
- Law enforcement officer (LEO) body dimensions have changed considerably over the past 46 years with a minor change in stature. The new dataset can be used for improving LEO vehicle and PPE design.
- The magnitudes of difference in some LEO dimensions measured over clothing and with gear as compared to semi-nude measurements were sizeable. The mean values show an increase of 105 mm in Hip Breadth (sitting) for men and 70 mm for woman, 91 mm in waist breadth for men and 120 mm for women, 45 mm in chest depth for men and 41 mm for women, 29 mm in shoulder breadth for men and 31 mm for women, and 11 kg in gear for men and 9 kg for women. The information is important for LEO cruiser cab space and ingress/egress modeling.
- LEOs have a notable upper torso build as compared to the general population for both men and

women. Using the new LEO anthropometry data rather than existing civilian anthropometry data for LEO equipment design is suggested.

ACKNOWLEDGMENTS

The authors extend their appreciation to the entire research team members, collaborators, and many others who provided technical and administrative support to this research project. Mr. James Green contributed to a part of the data collection. Dr. Tony McKenzie contributed to data collection equipment design and transport and data-collection trailer maintenance. Mr. Gene Hill provided administrative support and travel arrangements for the data collection team. Ms Tsui Ying Kau of the Number Sense Inc. provided statistical consultation on the design of this study. The authors are also indebted to many industrial partners, stakeholders, and others who provided keen insight and helpful suggestions to this study: National Sheriffs' Association (NSA), Fraternal Order of Police (FOP), International Association of Chiefs of Police (IACP), State University of New York at Buffalo, Morgantown Police Department (WV), National Institute of Justice (NIJ), Federal Law Enforcement Training Centers (FLETC), Federal Law Enforcement Officers Association (FLEOA), Saint Paul Police Department (SPPD), U.S. Army Natick Soldier Research, Development, and Engineering Center (NSRDEC), National Institute of Standards and Technology (NIST), Laurel Fraternal Order of Police (MD), Taunton Police Department (MA), Newport News Police Department (VA), Milwaukee Police Training Academy (WI), St Paul Police Department (MN), Denver Police Department (CO), Phoenix Police Department (AZ), Salt Lake City Police Department (UT), Oklahoma City Police Training Center (OK), Charlotte-Mecklenburg Police Department (NC), Memphis Police Department (TN), and Dayton Police Department (OH). Finally, the authors extend their appreciation to peer reviewers (including NIOSH internal and external and Human Factors Journal reviewers) of this manuscript for their comments and suggestions.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH or CDC.

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APPENDIX 1: SEMI-NUDE MEASUREMENTS VERSUS MEASUREMENTS WITH GEAR (ENCUMBERED MEASUREMENTS)

Bideltoid breadth, sitting buttock height buttock–knee length buttock–popliteal length

Chest breadth chest circumference chest depth crotch height

Elbow rest height, sitting eye height, sitting foot breadth, horizontal foot length

Grip strength, sitting (kg) hand breadth hand length head arc length

Head breadth head circumference head length hip breadth, sitting

Hip circumference knee height, sitting nuchal height, sitting popliteal height

Sitting height stature thigh circumference thumbtip reach

Waist breadth, sitting waist breadth ht, sitting waist circumference (o) waist front length, sitting

Waist height (omphalocele) weight (kg)

Abdominal extension acromion–trochanter bideltoid breadth bi-trochanter

Depth surface length surface length

Boot breadth boot length buttock-boot tip length chest breadth

Chest depth hip breadth shoulder-grip length stature with boots

Thigh clearance waist breadth weight, (kg), gear

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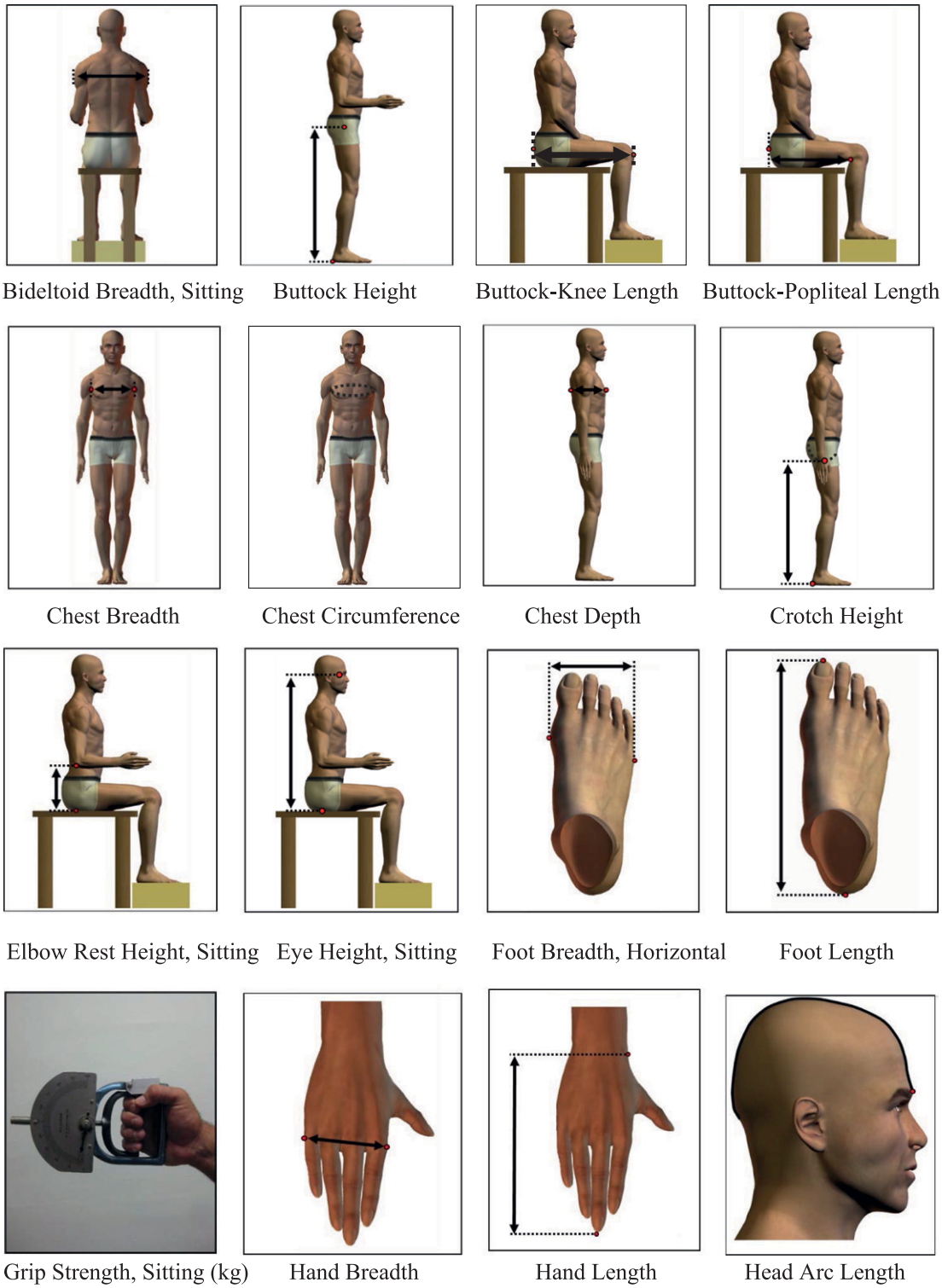
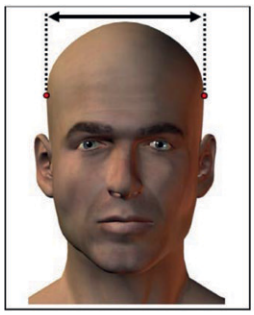
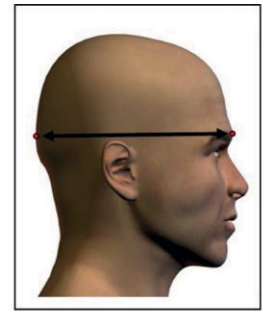
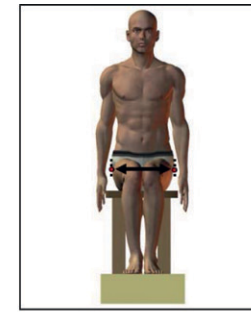


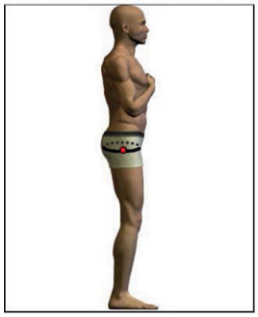
Figure A1. Semi-Nude Measurements vs. Measurements with Gear (Encumbered Measurements)

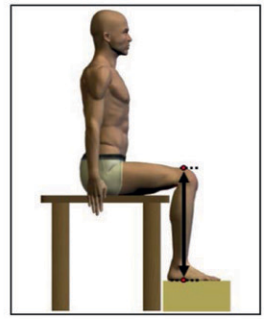

Head Breadth

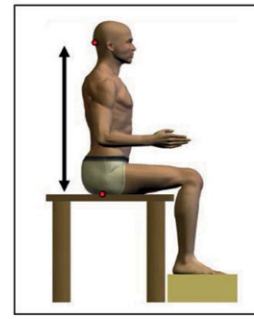

Head Circumference

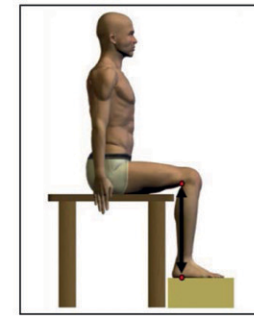

Head Length

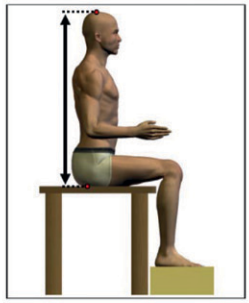

Hip Breadth, Sitting

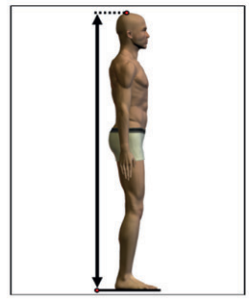

Hip Circumference

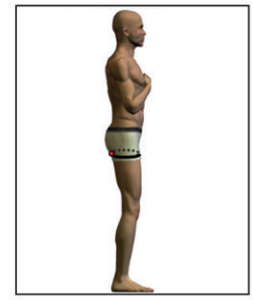

Knee Height, Sitting

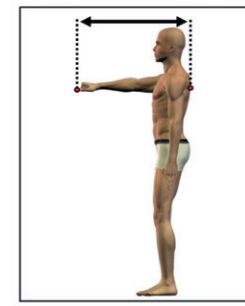

Nuchal Height, Sitting

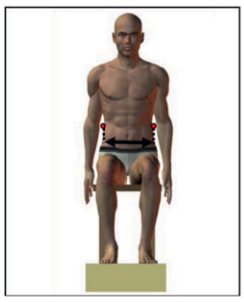

Popliteal Height

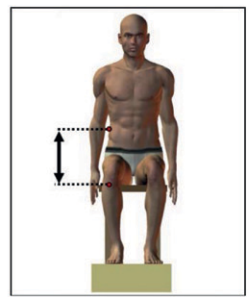

Sitting Height

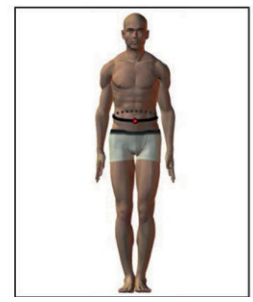

Stature


Thigh Circumference


Thumbtip Reach


Waist Breadth, Sitting


Waist Breadth Ht, Sitting


Waist Circumference (O)

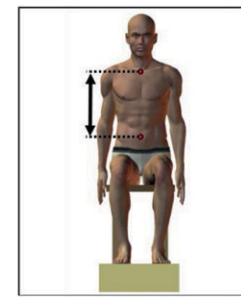
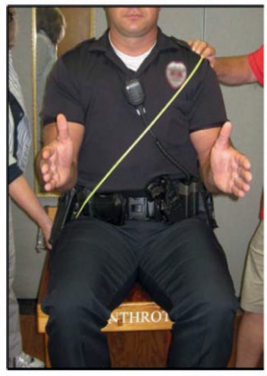

Waist Front Length, Sitting

Figure A1. Continued.

Waist Height (Omphalocele)

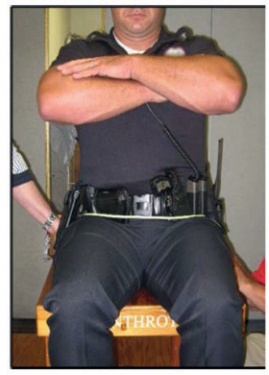
Weight (kg)

Abdominal Extension Depth



Acromion-Trochanter Surface Length

Bideltoid Breadth



Bi-trochanter Surface Length

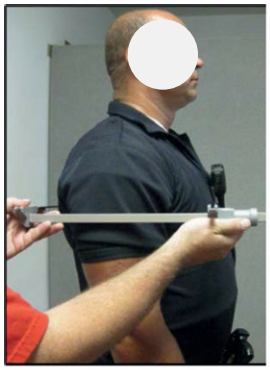
Boot Breadth

Boot Length

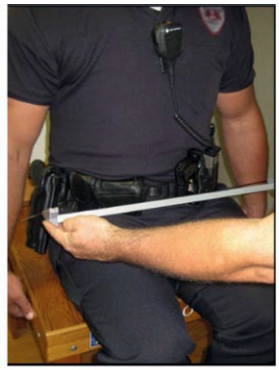
Buttock-Boot Tip Length

Chest Breadth

Figure A1. Continued.

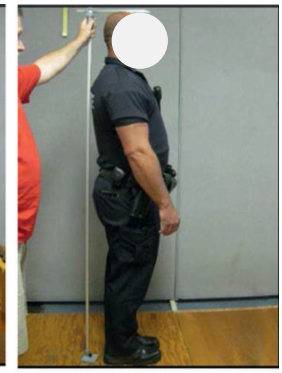


Chest Depth

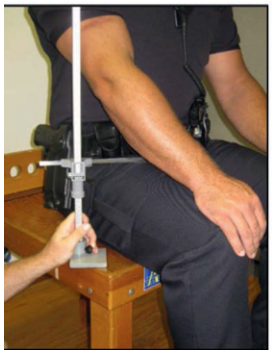


Hip Breadth

Shoulder-Grip Length



Stature with Boots



Thigh Clearance

Waist Breadth

Weight, (kg), gear

Figure A1. Continued.

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Date received: September 1, 2021
Date accepted: November 12, 2021