

Needs and Procedures for a National Anthropometry Study of Law Enforcement Officers

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Objectives: This research aims to determine the need and extent for a national anthropometry survey of law enforcement officers (LEOs) via an exploratory investigation of anthropometric changes of LEOs in four decades and comparisons of the LEO data with three existing military and civilian anthropometry sources.

Background: The best available anthropometric dataset of LEOs is 45 years old and has largely become outdated due to demographic changes. Assessing the extent of anthropometric changes of LEOs through a sample and evaluating the differences of the sample against existing anthropometric datasets is a step toward ascertaining the necessity for a national LEO anthropometry study.

Method: Thirty-two body dimensions of 67 regional male LEOs and seven female LEOs were measured, and the data of males were compared with the best available LEO anthropometry data from 1975 and three recent non-LEO anthropometry databases.

Results: Anthropometric dimensions were significantly different between this LEO study and existing data sources, especially in chest circumference and body weight. Most of the significant differences are important differences for LEO protective gear and vehicle design.

Conclusion: The study confirmed that the existing 45-year-old LEO dataset and recent Army and civilian datasets would not be suitable for armor and equipment design for the current LEO population.

Application: The study results are useful in supporting the decision of investing in a national LEO anthropometry survey and for equipment manufacturers to recognize the distinctiveness of LEO anthropometry from other populations and the magnitude of anthropometry changes of LEOs over the past 45 years.

Keywords: police, body size, vest, vehicle, egress

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INTRODUCTION

Approximately 745,000 to 900,000 law enforcement officers (LEOs) serve in the United States (National Law Enforcement Officers Memorial Fund, 2017; U.S. Census Bureau, 2018). During 2003–2009, 968 officers died in the line of duty; 48% of the fatalities were associated with traffic-related crash incidents and 44% were connected to violent acts (Tiesman et al., 2013). In addition, LEOs were among the four occupations with a nonfatal injury incidence rate greater than 400 cases per 10,000 full-time workers in 2011–2015 (U.S. Bureau of Labor Statistics, 2016). Of these nonfatal injuries to LEO, 20% were related to transportation incidents and 27% were associated with violent acts.

Literature has pointed to some critical aspects for improvement to reduce LEO vehicle crashes and increase incident survivability, including seatbelt design and use (NHTSA, 2011; Oron-Gilad et al., 2005; Stafford et al., 2004), seat arrangement (Donnelly et al., 2009), patrol vehicle cab and equipment configurations (International Association of Chiefs of Police, 2011; Jones et al., 2015; Kun et al., 2004), seatbelt–body armor interface (Granberg, 2001), patrol vehicle ingress and egress arrangements (McKinnon et al., 2011), and overall patrol car design (Dorn & Brown, 2003; Ludwig, 1970; Molenbroek et al., 2009). Aside from ensuring a good fit between LEOs and their vehicles, body armor, helmets, gloves, and boots are important elements of an integrated LEO personal protective system, especially for handling violent acts. Poor equipment fit may compromise protective capabilities of personal protective equipment (PPE) and may result in LEOs not wearing the PPE because of discomfort (Kwon et al., 2003). In addition, “by establishing an anthropometric database for LEOs,

the designers and manufacturers of these types of equipment will be able to produce more effective products and reduce the problems associated with sizing and stocking these items” (Martin et al., 1975). All these issues point to the need for a human factors engineering intervention in the vehicle–apparatus–driver interfaces and PPE design. A key component of the intervention is the application of anthropometric data representative of current LEOs.

The National Bureau of Standards (NBS) released its landmark anthropometric data of LEOs in 1975 (Martin et al., 1975). The data have largely become outdated due to demographic changes (e.g., sex and race/ethnicity) that have occurred in the past 45 years. Whereas motor vehicle and PPE industries have taken steps to integrate recently available population-based anthropometric data for general vehicle and PPE applications, the data are not necessarily suitable for LEO vehicle and PPE designs; protective service workers (i.e., firefighters, police, and guards) were reported to be bigger than those in all occupations combined (Hsiao et al., 2002).

Establishing any national anthropometry database of a special occupational group can be challenging and costly. Defining the extent and justification for a survey is a critical step for conducting a successful national study. This paper presents an exploratory investigation of LEO anthropometry to determine whether anthropometric changes of LEOs over the past four decades are significant and whether other existing anthropometry sources might provide suitable data for law enforcement equipment design to define the extent or need for a national LEO anthropometry survey. The study results are useful (1) for an organizational decision on investing in a national LEO survey, (2) as a template for other organizations who may need to conduct similar studies, and (3) for researchers and practitioners in the anthropometry field and manufacturers of LEO equipment to be aware of the potential distinctiveness of LEO anthropometry.

OBJECTIVE

The primary objectives of this assessment of LEO anthropometry were to determine (1) whether anthropometric changes of LEOs over

the past four decades are significant, and (2) whether other existing anthropometry sources (such as recent military personnel anthropometry and general population anthropometry) might provide suitable data for law enforcement equipment design. The results would define the need for or extent of a nationwide LEO anthropometry survey. A secondary objective was to apprehend the magnitude of difference in dimensions measured over clothing and with gear as compared with nude measurements, known as encumbered anthropometry (Garlie & Choi, 2014), which will be valuable for in-vehicle workspace layout (Hsiao et al., 2015), vehicle ingress and egress configurations, PPE design, and PPE–LEO interface digital modeling applications.

METHODS

Participants

Seventy-four LEOs from West Virginia comprised the measurement sample for this study. The sample included 67 men and seven women. As the female officers were so few in number in this study, we focus our reporting on results of the male officers in this paper. Nearly all the officers were White. Two officers were African American, and one was Hispanic. The age distribution of the sample is skewed to younger officers; approximately 61% (41/67) were 22–34 years old, 21% (14/67) were 35–44 years old, and 18% (12/67) were 45–56 years old. Since these participants were all recruited from one local area (Morgantown, WV), this sample cannot be considered representative of the larger LEO population. Nevertheless, through a weighted sampling process, it served the purposes of testing the protocol for a larger study and suggesting where current dimensions differ from those measured in 1975, which are the best available LEO anthropometry data. This research complied with the National Institute for Occupational Safety and Health (NIOSH) Code of Ethics and was approved by the Institutional Review Board at NIOSH. Informed consent was obtained from each participant.

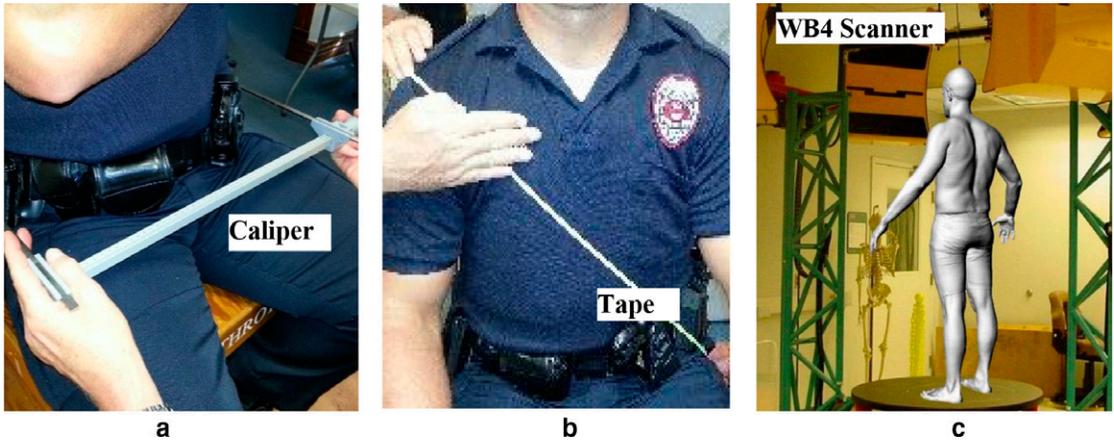


Figure 1. Participants were measured with duty uniform and gear (1a and 1b) and in minimal clothing (1c), using traditional anthropometric calipers (1a), anthropometric tapes (1b), and a whole-body WB4 scanner (1c).

Study Procedure

Each participant was measured for 32 seated and standing dimensions selected for their application to the amelioration of specific design problems experienced by officers seated in LEO vehicles and wearing protective equipment such as seat belts and protective vests. Measurements included 19 nude dimensions (with participants in minimal clothing) and 13 dimensions measured with participants dressed in full professional gear; five of the dimensions were measured both nude and in-gear (Figure 1a, b and c). An anthropometer/caliper (GPM, Switzerland; Figure 1a), two traditional steel tape measures (Lufkin Inc., US; Figure 1b), an electronic scale (MedWeigh, US), and a dynamometer (Takei, Japan; for measuring grip strength) were used to obtain the data in this study. In addition, a Cyberware WB4 three-dimensional (3D) full-body scanner (Figure 1c) was used to obtain four 3D scans of participants while they were standing and seated, with and without their duty uniform and the gear used in their daily work.

Two experienced measurers collected the traditionally measured data. They were first trained using the allowable intra- and inter-measurer errors described in the Gordon et al. (1989) and Hotzman et al. (2011) studies as a benchmark. A measuring station for the traditional measurements was set up at the NIOSH facility in Morgantown, WV. As each participant arrived,

he or she was provided with an explanation of the study and given the opportunity to ask questions. Participants who agreed to take part in the survey were given consent forms to sign, and their demographic information was recorded. They then changed into shorts.

Before the first set of measurements was taken, an investigator located a number of landmarks by palpating the bones of the participant and placing marks on the skin with an eyeliner pencil. Six standing and 13 sitting measurements were then taken. Measurements were subjected to a two-part editing program during data collection as they were entered into a laptop computer. Software detects possible measurement or recording errors and signaled to the measurer. The measurement can be retaken while the subject is still available. The error-detection software algorithms comprise of a combination of outlier identification and regression procedures based on existing anthropometry databases.

After the nude dimensions were taken, the participants moved on to the 3D scanner station, where standing and seated body scans were taken. Participants then donned their duty uniform and the gear used in their daily work before returning for the second set of 13 traditional measurements. Finally, participants were scanned in full gear before changing back into street clothes, compensated for their time, and

released. As the previous data sources (Martin et al., 1975) to be compared were all traditional measurements, this report is concerned mainly with the traditional measurement data. The 3D scans were used as a means to check the measurements as needed in this report, especially the “body shape” information—chest, waist, and hip circumferences.

DATA ANALYSIS

Weighted Sampling

Before data were analyzed, a weighting procedure was applied to the sample to ensure that the current sample characterizes the current LEO population in age composition. There were 744,674 LEOs in 2016 in the United States with a distribution of 13.3% females and 86.7% males (U.S. Census Bureau, 2018). Of the LEOs, 79% were White, 13% Black, and 8% Hispanic and other. They were about evenly distributed among three age groups: 16–34, 35–44, and ≥ 45 . This study sample is not diverse enough (mainly White males) for application of race/ethnicity weighting, but it is feasible for age-related weighting. The age distribution of the sample was skewed to younger LEOs at approximately 61% (41/67) age 22–34, 21% (14/67) age 35–44, and 18% (12/67) age 45–56. The weight is calculated as the relative frequency of a given age cell in the LEO population, divided by the relative frequency of the same cell in the survey sample. It can be expressed as

$$\text{Weight}_i = [N_i / (N_1 + N_2 + \dots + N_i)] / [n_i / (n_1 + n_2 + \dots + n_i)],$$

where N is the count from the age cell in the LEO population, n is the count from the age cell in the survey sample, and i is the subscript for the age group. In this study, participants were 22 to 56 years old. There were 580,971 male LEOs in this age group in 2016 in the United States (U.S. Census Bureau, 2018). The weightings would be $(222954/580971)/(41/67) = .62712$ for the 22–34 age group, $(200414/580971)/(14/67) = 1.65090$ for the 35–44 age group, and $(157,603/580971)/(12/67) = 1.51462$ for the 45–56 age group. In other words, each

participant in the 22–34 age group would be counted as 0.62712 persons. Correspondingly, each participant in the 35–44 age group represented 1.65090 persons, and each one in the 45–56 age group denoted 1.51462 persons.

Current LEOs Compared With Four U.S. Anthropometry Data Sources

LEOs were last measured for their body dimensions in 1975 (Martin et al., 1975), and designs for vehicles and equipment have been based on those data since that time. This study provides an opportunity to document whether, and to what extent, the body dimensions of LEOs have changed. We have identified 10 dimensions whose descriptions are the same between the Martin et al. (1975) study and the present one. It should be noted that the Martin et al. (1975) study reported only un-weighted data results. Another data source for comparison was the U.S. Army Anthropometric Survey (ANSUR 2; Gordon et al., 2014) for armor design applications. There are 13 dimensions whose descriptions are the same between ANSUR 2 and the present LEO study. It should be noted that the demographic distribution (race and age) is different between the army and civilian LEOs and that the army data lack sufficient age range to reweight effectively. Therefore, the comparisons were mainly on the difference of means of the two groups for each dimension. We next performed a similar analysis comparing the present study sample to the U.S. civilian population as represented by the Civilian American and European Surface Anthropometry Resource (CAESAR) dataset (Harrison & Robinette, 2002). Weighted CAESAR data were used. There are 12 comparable dimensions between the present LEO study and CAESAR. It must be noted that the CAESAR “waist circumference” data were measured at the “preferred” waist location for specific clothing applications, rather than at the omphalion as in other databases; the CAESAR waist circumference would be smaller. The CAESAR waist circumference thus is not included in the list of the 12 comparable dimensions. A more recent civilian anthropometry dataset with a better representation of the US civilians than CAESAR is available (i.e.,

the National Health and Nutrition Examination Survey – NHANES; Fryar et al., 2016). The nutrition-oriented dataset contains only four comparable dimensions (stature, weight, body mass index, and waist circumference) with the present LEO study. Although the dataset would be insufficient to address some unique body characteristics of LEOs (such as chest circumference and bideltoid breadth), the data on stature, weight, and waist circumference may still reveal some insights on differences in body characteristics between LEOs and general civilians. A two-tailed t-test with a p value of .05 as the significance level was performed for each dimension for all comparisons.

RESULTS

Summary Statistics of the Measured Dimensions

The summary statistics for the nude measurements and dimensions measured over clothing and with gear are listed in Table 1. Both unweighted and weighted results are presented.

Current LEOs Compared With 1975 LEO Data Source

Table 2 shows the results of t-test comparisons of means between the current and Martin et al. (1975) studies for nude measurements. The Martin et al. dataset of 1975 contained only nude measurements. Eight of the 10 dimensions are different at the two-tail $\alpha = .05$ statistical significance level ($p = .05/10 = .005$ for ten paired comparisons). Stature is basically equivalent and sitting height is not statistically different. In every case that is significantly different, the present study measurement is larger than the earlier Martin measurement. The differences are especially marked in the torso and four of them are related to the 13.6 kg increase in average weight (weighted sample). The differences of 103 mm in chest circumference, 122 mm in waist circumference, 26 mm in shoulder breadth, and 4.3 in body mass index have important implications in protective vest, seatbelt, vehicle ingress/egress, and uniform designs. The 14-mm difference in buttock-knee length and 20-mm difference in knee height (sitting) have an important influence on vehicle

cab and seat configurations. These results, if confirmed by a larger study, suggest that relying on the Martin et al. (1975) for current and future design of law enforcement vehicles and PPE may lead to inaccurate results.

Current LEOs Compared With Army Data Source

Comparisons between current LEOs and army data source (ANSUR 2 survey; Gordon et al., 2014) at two-tail $\alpha = .05$ statistical significance level ($p = .05/13 = .0038$ for thirteen paired comparisons) are shown in Table 3. Eleven of 13 dimensions are significantly different between ANSUR 2 and the present LEO study. The LEOs are 27 mm taller and 11.4 kg heavier, and are larger on every dimension, except for popliteal height and crotch height. The body shapes of the LEO population are quite different from the Army population; the LEO chest circumference is 66 mm larger and the waist circumference is 86 mm larger on the mean. The larger stature for 27 mm and knee height (sitting) for 25 mm signify the body-size difference of LEO in another vector. The results suggest that the ANSUR 2 dataset would not be suitable for LEO equipment design applications, especially for body armors and seatbelts.

Current LEOs Compared With U.S. General Population—CAESAR

There are 12 comparable dimensions between the present LEO pilot study and CAESAR, and nine of the 12 dimensions are significantly different at the two-tail $\alpha = .05$ statistical significance level ($p = .05/12 = .004$ for 12 paired comparisons; Table 3). The body weight of the LEO sample is larger than the civilian mean by 13.7 kg. Another important difference is the mean chest circumference; the dimension for LEOs is larger than the CAESAR civilian sample by 101 mm. The difference in hip circumference is also important but at a smaller scale of 44 mm. The mean values of head circumference, sitting height, and stature of LEOs are not statistically different from the CAESAR civilian samples, although they are larger by 4, 8, 16 mm, respectively (Figure 2).

TABLE 1: Summary Statistics of the Measured Dimensions (Male Law Enforcement Officers; Weight, and Grip Strength in kg; All Other Values in mm)

Dimension	Unweighted				Weighted				
	N	Mean	Std Dev	Std Error	N	Mean	Std Dev	Std Error	
Nude measurement	Bideltoid breadth, sitting	67	518	32	3.9	92	521	32	3.3
	Buttock-knee length	67	631	27	3.3	92	629	25	2.6
	Chest circumference	67	1114	101	12.3	92	1125	100	10.4
	Crotch height	67	849	47	5.7	92	846	46	4.8
	Waist front length, sitting	67	401	29	3.5	92	402	29	3.0
	Grip strength, sitting (kg)	67	119	20	2.5	92	118	21	2.2
	Head arc length	67	363	14	1.7	92	362	13	1.4
	Head circumference	67	580	17	2.1	92	581	17	1.8
	Hip breadth, sitting	67	390	30	3.7	92	390	28	3.0
	Hip circumference	67	1074	79	9.7	92	1076	75	7.8
	Knee height, sitting	67	579	26	3.2	92	579	25	2.6
	Nuchal height, sitting	66	793	34	4.2	91	791	33	3.5
	Popliteal height	66	428	22	2.7	90	427	22	2.3
	Sitting height	67	931	34	4.2	92	929	33	3.4
	Stature	67	1786	70	8.5	92	1783	67	6.9
	Waist breadth height, sitting	67	241	13	1.6	92	239	13	1.4
	Waist breadth, sitting	67	349	39	4.8	92	353	37	3.9
	Waist circumference (omphalocele level)	67	1014	120	14.6	92	1027	113	11.8
	Weight (kg)	67	95.9	16	1.93	92	96.9	15	1.6
	Measurement with gear	Weight (kg), gear	67	105.9	16	1.95	92	106.9	16
Stature, footwear, gear		67	1804	104	12.6	92	1797	113	11.8
Chest width, gear		67	372	32	3.9	92	375	32	3.4
Chest depth, gear		67	312	27	3.2	92	314	27	2.8
Buttock-shoetip length, sitting		67	834	40	4.9	92	830	40	4.2
Shoulder-grip length, sitting		67	924	35	4.2	92	825	34	3.5
Bideltoid breadth, sitting		67	530	32	3.9	92	532	32	3.3
Abdominal extension depth, sitting		67	347	35	4.2	92	350	34	3.5
Waist breadth, sitting		67	427	51	6.3	92	431	49	5.1
Hip breadth, sitting		67	497	35	4.3	92	496	34	3.6
Thigh clearance, sitting		67	185	15	1.8	92	185	15	1.5
Acromion-trochanter surface length, sitting		67	813	41	5.0	92	815	42	4.3
Bi-trochanter surface length, sitting		67	684	45	5.5	92	687	45	4.7

Current LEOs Compared With U.S. General Population—NHANES

There are four comparable dimensions between the present LEO study and NHANES,

and three of the four dimensions are significantly different at the two-tail $\alpha = .05$ statistical significance level ($p = .05/4 = .0125$ for four paired comparisons; Table 4). The body weight of the LEO sample is larger than the civilian

TABLE 2: Summary Statistics of the Current Study of Law Enforcement Officers Compared With Martin et al. (1975) Law Enforcement Survey: Males (Weight in kg; No Unit for Body Mass Index; All Others in mm)

Dimension	Survey	N	Mean	Std Dev	Std Error	NIOSH - Martin
Body mass index	Martin 1975	2989	26.2	3.3	0.1	4.3
	NIOSH-LEO (weighted)	92	30.5	4.4	0.5	
Buttock-knee length	Martin 1975	2988	615	27	0.5	14
	NIOSH-LEO (weighted)	92	629	25	2.6	
Chest circumference	Martin 1975	2990	1022	79	1.4	103
	NIOSH-LEO (weighted)	92	1125	100	10.4	
Head circumference	Martin 1975	2985	575	16	0.3	6
	NIOSH-LEO (weighted)	92	581	17	1.8	
Knee height, sitting	Martin 1975	2984	559	25	0.5	20
	NIOSH-LEO (weighted)	92	579	25	2.6	
Shoulder breadth (Bideltoid)	Martin 1975	2985	495	29	0.5	26
	NIOSH-LEO (weighted)	92	521	32	3.3	
‡Sitting height	Martin 1975	2993	922	34	0.6	7‡
	NIOSH-LEO (weighted)	92	929	33	3.4	
‡Stature	Martin 1975	2989	1781	58	1.0	2‡
	NIOSH-LEO (weighted)	92	1783	67	6.9	
Waist circumference	Martin 1975	2988	905	94	1.7	122
	NIOSH-LEO (weighted)	92	1027	113	11.8	
Weight (kg)	Martin 1975	2991	83.3	11.9	0.2	13.6
	NIOSH-LEO (weighted)	92	96.9	15.4	1.6	

Note. * indicates significantly different from each other (two-tail t-test at significance level of 0.05 with $p = .05/10 = .005$ for ten paired comparisons with $z = 2.81$). ‡ indicates no significant difference from each other. LEO = law enforcement officer; NIOSH = National Institute for Occupational Safety and Health.

mean by 8.1 kg and the LEO sample is taller by 26 mm. Also, the body mass index of LEO sample is larger by 1.8. These differences are important differences in protective gear design applications. The mean waist circumference for LEOs is not statistically different from the NHANES civilian samples, although the mean waist circumference for LEOs is slightly larger by 12 mm.

Dimensions Measured Over Clothing and With Gear as Compared With Nude Measurements

This study collected anthropometric data of five measurements on the same individuals in both nude and clothed conditions, which allows an assessment of the additional size and bulk

added by the uniform and accompanying gear. The measurement references for the nude and in-gear measurements are similar enough that direct comparisons can be made. Table 5 shows the values computed by subtracting the nude value from the clothed value. The mean values show an increase of 106 mm in hip breadth (sitting) and 10 kg in weight, which are great differences at the two-tail $\alpha = .05$ statistical significance level ($p = .05/5 = .01$ for five paired comparisons). Although the increase of 11 mm in the mean value of bideltoid breadth, 14 mm in stature (i.e., shoe height), and 12 mm in waist breadth (sitting) are not statistically significant, they have important implications in LEO vehicle cab-space and egress designs as the spaces are typically very tight.

TABLE 3: Summary Statistics of the Study of Male Law Enforcement Officers Compared With ANSUR 2 Males and CAESAR Males (Weight in kg; All Other Values in mm)

Dimension	Survey	N	Mean	Std Dev	Std Error	Difference in Mean
Hip breadth, sitting	ANSUR 2*	4082	379	30	.5	11*
	NIOSH-LEO (weighted)	92	390	28	3.0	–
	CAESAR*	1117	376	38	1.1	14*
Knee height, sitting	ANSUR 2	4082	554	28	.4	25*
	NIOSH-LEO (weighted)	92	579	25	2.6	–
	CAESAR*	1114	493	31	0.9	86*
Popliteal height	ANSUR 2 [†]	4082	430	25	.3	–3 [†]
	NIOSH-LEO (weighted)	90	427	22	2.3	–
Sitting height	ANSUR 2*	4082	918	36	.6	11*
	NIOSH-LEO (weighted)	92	929	33	3.4	–
	CAESAR [†]	1119	921	43	1.3	8 [†]
Stature	ANSUR 2*	4082	1756	69	1.1	27*
	NIOSH-LEO (weighted)	92	1783	67	6.9	–
	CAESAR [†]	1119	1767	76	2.3	16 [†]
Waist circumference	ANSUR 2*	4082	941	112	1.8	86*
	NIOSH-LEO (weighted)	92	1027	113	11.8	–
Waist front length, sitting	ANSUR 2*	4082	388	29	.5	14*
	NIOSH-LEO (weighted)	92	402	29	3.0	–
	CAESAR*	1119	462	53	1.6	–60*
Weight (kg)	ANSUR 2*	4082	85.5	14.2	.2	11.4*
	NIOSH-LEO (weighted)	92	96.9	15.4	1.6	–
	CAESAR*	1119	83.2	17.4	0.5	13.7*
Hip circumference	NIOSH-LEO (weighted)	92	1076	75	7.8	–
	CAESAR*	1119	1032	98	2.9	44*

Note. * indicates significantly different from each other (two-tail t-test at significance level of 0.05 with $p = .05/13 = .0038$ for 13 paired NIOSH LEO-ANSUR 2 comparisons with $z = 2.9$, and $p = .05/12 = .004$ for 12 paired NIOSH LEO-CAESAR comparisons with $z = 2.88$). † indicates no significant difference from each other. ANSUR 2 = U.S. Army Anthropometric Survey; CAESAR = Civilian American and European Surface Anthropometry Resource; LEO = law enforcement officer; NIOSH = National Institute for Occupational Safety and Health.

DISCUSSION

Anthropometric Changes of LEOs Over the Past Four Decades

Although the changes in stature and sitting height of LEOs are not significant over the past four decades, the changes in other dimensions are substantial. The increases of 13.6 kg in mean weight, 103 mm in chest circumference, 122 mm in waist circumference, 26 mm in shoulder breadth, and 4.3 in body mass index together signify an evolution of LEO body size and shape over the past four decades. There

are several implications for these changes in LEOs' body dimensions. First, the larger chest, waist, and shoulder dimensions have an important impact on sizing structure and design of protective vests and uniforms. Although each vest size may cover a range of 63 mm for chest width, a difference of 25 mm in chest width (or 51 mm in chest circumference) or 114 mm in waist circumference can result in a full-size shift for vests (U.S. Department of Justice, 2014). Similarly, typical apparel and uniform sizing charts specify that a size of shirt would

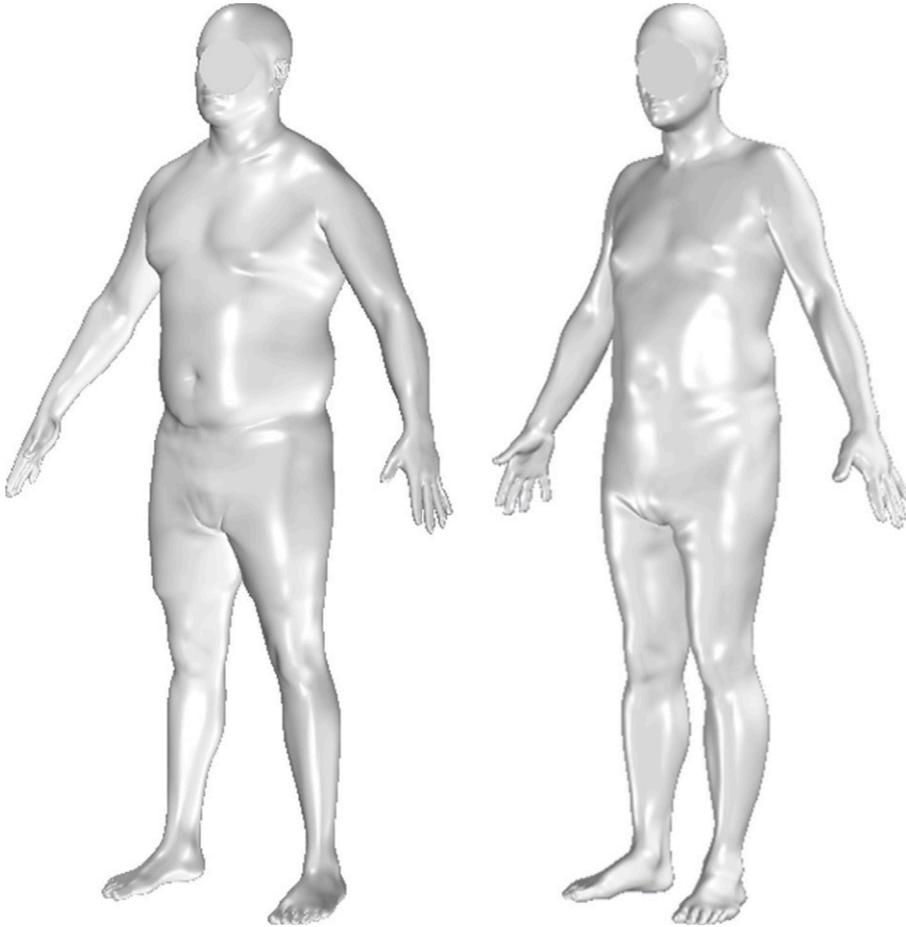


Figure 2. A “near-average” male LEO who is 1769 mm in body height and 95.0 kg in body weight (left) comparing to a “near-average” male CAESAR general civilian who is 1759 mm in body height and 83.2 kg in body weight (right). LEOs are in general heavier than the general population and have a well-built upper torso. The mean body height and weight are 1783 mm and 96.9 kg for male LEOs, and 1767 mm and 83.2 kg for male CAESAR general civilian. The mean statures of LEOs and CAESAR general civilians are not statistically different. CAESAR = Civilian American and European Surface Anthropometry Resource; LEO = law enforcement officer.

accommodate a range of 76 mm chest circumference and a size of pants would cover a range of 51 mm for waist circumference. The 103-mm difference in chest circumference and 122-mm difference in waist circumference mean a two size shift in a uniform sizing system. Second, the larger buttock-knee length (14 mm) and knee height (sitting; 20 mm) have a significant effect on police cruiser cab equipment arrangement and seat configuration as LEOs’

cruiser cab space is very tight. Third, the 103-mm increase in mean chest circumference and 122-mm growth in waist circumference have a significant implication in police vehicle ingress/egress configuration or entry/exit procedure. Patrol officers were reported to spend 43.22% of their time inside their vehicles, 55.5% out of vehicles, and 1.28% in entering and exiting vehicles (McKinnon et al., 2011). With larger waist and chest and frequent necessities for

TABLE 4: Summary Statistics of Law Enforcement Officers Compared With NHANES Survey: Males (Weight in kg; No Unit for Body Mass Index; All Others in mm)

Dimension	Survey	N	Mean	Std Error	NIOSH -NHANES
Body mass index	NHANES	5223	28.7	0.13	1.8
	NIOSH LEO (weighted)	92	30.5	0.5	–
Stature	NHANES	5232	1757	2.1	26
	NIOSH-LEO (weighted)	92	1783	6.9	–
Weight (kg)	NHANES	5236	88.8	0.43	8.1
	NIOSH-LEO (weighted)	92	96.9	1.6	–
‡Waist circumference	NHANES	5018	1015	3.9	12‡
	NIOSH-LEO (weighted)	92	1027	11.8	–

Note. * indicates significantly different from each other (two-tail t-test at significance level of 0.05 with $p = .05/4 = .0125$ for four paired comparisons with $z = 2.5$). ‡ indicates no significant difference from each other. LEO = law enforcement officer; NHANES = National Health and Nutrition Examination Survey; NIOSH = National Institute for Occupational Safety and Health.

TABLE 5: Summary Statistics of the Measured Dimensions for the In-Gear and Nude Conditions (Weighted) (Male Law Enforcement Officers; Weight in kg; All Other Values in mm)

Dimension	With Clothing, Gear, and Footwear				Nude Measurement				With Gear—Nude
	N	Mean	Std Dev	Std Error	N	Mean	Std Dev	Std Error	
Bideloid breadth, sitting	92	532	32	3.3	92	521	32	3.3	11‡
Hip breadth, sitting	92	496	34	3.6	92	390	28	3.0	106*
Stature	92	1797	113	11.8	92	1783	67	6.9	14‡
Waist breadth, sitting	92	431	49	5.1	92	353	37	3.9	12‡
Weight (kg)	92	106.9	16	1.6	92	96.9	15	1.6	10*

Note. * indicates significantly different from each other (2-tail t-test at significance level of 0.05 with $p = .05/5 = .01$ for five paired comparisons with $z = 2.675$). ‡ indicates no significant difference from each other.

vehicle entry and exit among current LEOs, an innovative ingress/egress configuration or entry/exit procedure is needed. A new national anthropometry survey with a larger sample size than this exploratory investigation and covering more anthropometric measurements is warranted for safe LEO armor and vehicle designs. Using the available 3D anthropometry scanners, the new anthropometry survey can better catch the body shape configurations of LEOs, which can be interrogated by law enforcement agencies and equipment designers for improved LEO gear design.

Women made up 5.0% of the LEOs in 1980 (Cordner & Cordner, 2011) and 13.3% in 2016

(U.S. Census Bureau, 2018). The anthropometry study of LEOs in 1975 (Martin et al., 1975) did not include female LEOs. The sample distributions of race/ethnicity in the Martin et al. (1975) study were 83.7% White, 9.8% Black, and 6.4% Hispanic and other. The LEOs in 2016 in the United States were 79% White, 13% Black, and 8% Hispanic and other (U.S. Census Bureau, 2018). The sample distribution of age in the Martin et al. (1975) study was 75.4% 18–34 years old, 15.3% 35–44 years old, and 9.3% ≥45 years old. The present LEO study sample was 61% 22–34 years old, 21% 35–44 years old, and 18% 45–56 years old. The Martin et al. (1975) study did not calculate or apply an age-related

TABLE 6: Differences in Anthropometric Dimensions Among Male LEOs and ANSUR 2, CAESAR, and NHANES Males (Weight in kg; No Unit for Body Mass Index; All Other Values in mm)

Dimension	LEO Subtracts ANSUR 2	LEO Subtracts CAESAR	LEO Subtracts NHANES
Bideltoid breadth	11*	31*	–
Buttock-knee length	11*	15*	–
Chest circumference	66*	101*	–
Crotch height	13‡	62*	–
Head circumference	7*	4‡	–
Hip breadth, sitting	11*	14	–
Knee height, sitting	25*	86*	–
Popliteal height	–3‡	–	–
Sitting height	11*	8‡	–
Stature	27*	16‡	26*
Waist circumference	86*	–	12‡
Waist front length, sitting	14*	–60*	–
Weight (kg)	11.4*	13.7*	8.1*
Hip circumference	–	44*	–
Body mass index	–	–	1.8*

Note. * indicates significantly different from each other. ‡ indicates no significant difference from each other. ANSUR 2 = U.S. Army Anthropometric Survey; CAESAR = Civilian American and European Surface Anthropometry Resource; LEO = law enforcement officer; NHANES = National Health and Nutrition Examination Survey.

weighting in their report. The LEOs in 2016 in the United States were about evenly distributed among three age groups: 16–34, 35–44, and ≥ 45 (U.S. Census Bureau, 2018). The present LEO study used an age-related weighting but not race/ethnicity and sex weighting because the sample was not diverse enough (mainly White males). A new national LEO anthropometry survey representing the current sex, race/ethnicity, and age distribution of LEOs would be timely and necessary.

Differences Between This LEO Dataset and Existing Anthropometry Sources

Table 6 summarizes the differences in anthropometric dimensions between male LEOs and ANSUR2, CAESAR, and NHANES males. Both mean stature and body weight of LEOs are larger than those of ANSUR2, CAESAR, and NHANES, although stature difference between LEO and CAESAR (16 mm) is not statistically significant. The difference in stature is in the range of 0.9%–1.5%, whereas the difference in weight is in the range of 8.4%–14.1% using

the LEO data as the denominators, which indicate that LEOs on average are physically bigger than army personnel and general civilian populations. The difference in chest circumference of 66 mm (compared with ANSUR2) and 101 mm (compared with CAESAR) further signify that LEOs are more muscular in general. Interestingly, the difference in waist circumference between LEO and ANSUR2 is 86 mm, whereas the difference is only 12 mm between LEO and NHANES (statistically insignificant). These results lead to the supposition that army personnel are skinnier, and LEOs are in general heavier than the general population and have a well-built upper torso but not necessarily a larger belly. The negative difference of 60 mm in “waist front length—sitting” between LEO and CAESAR further confirms the supposition; waist front length (sitting) is defined as the “surface” distance between the suprasternal landmark and the anterior omphalion landmark (including belly) while seated. In short, there is an important shape difference in multiple dimensions between LEOs and the army and

TABLE 7: 95th Percentile Design Values for Law Enforcement Officers Compared With Martin et al. (1975), ANSUR 2, CAESAR and NHANES: Males (Weight in kg; All Other Values in mm)

Dimension (95th Percentile)	Martin et al. (N = 2985)	ANSUR 2 (N = 4082)	CAESAR (N = 1119)	NHANES (N = 5018)*	LEO (N = 92) Weighted
Buttock-knee length	662	669	673	–	670
Chest circumference	1158	1207	1210	–	1290
Head circumference	601	601	604	–	609
Knee height, sitting	602	602	607	–	620
Shoulder (bideloid) breadth	544	567	550	–	574
Sitting height	979	977	985	–	983
Waist circumference	1073	1131	–	1295	1213
Stature	1879	1870	1901	1881	1893
Weight (kg)	104.4	110.7	114.6	124.9	121.6
Crotch height	–	925	880	–	922
Hip breadth, sitting	–	431	435	–	436
Popliteal height	–	471	–	–	463
Waist front length, sitting	–	438	548	–	450
Hip circumference	–	1149	1194	–	1199

Note. * N = 5018, 5232, and 5236 for waist circumference, stature, and weight, respectively. ANSUR 2 = U.S. Army Anthropometric Survey; CAESAR = Civilian American and European Surface Anthropometry Resource; LEO = law enforcement officer; NHANES = National Health and Nutrition Examination Survey.

general civilian populations; this shape variation might better be captured and demonstrated in 3D scans in a large-scale national study.

Practical Implication of LEO Anthropometry for LEO Vehicle and PPE Design Decisions

LEO vehicle and PPE design decisions are not just based on mean values. Often, designs are targeted at higher and lower percentile values, that is, a 5th percentile female value and a 95th percentile male value. The 95th percentile male values for the comparable dimensions among Martin et al. (1975), ANSUR 2, CAESAR, NHANES, and this study are seen in Table 7. It shows that the 95th percentile values from this LEO study sample are larger than the earlier Martin et al. (1975) study and ANSUR 2 on each of the design dimensions except for crotch height and popliteal height for the ANSUR 2. The 95th percentile chest circumference and shoulder (bideloid) breadth are larger than those of the CAESAR. It is worth noting that the 95th percentile value of waist front length (including belly) of LEOs is 98 mm

smaller than that of CAESAR (no NHANES data), and the 95th percentile value of waist circumference of LEOs is 82 mm smaller than that of NHANES (no CAESAR data), whereas the 95th percentile value of Chest Circumference of LEOs is 132 mm, 83 mm, and 80 mm larger than that of Martin et al. (1975), ANSUR 2, and CAESAR, respectively. The differences have significant implications in LEO vehicle (such as cab space) and PPE (such as body armor) design (ASTM International, 2016).

Measurement Errors, Encumbered Anthropometry, and 3D Scans

It is reasonable to enquire whether the anthropometry measurers who were trained by different people, used different techniques, and did measurements decades apart could be a source of difference among the Martin et al. (1975), present LEO, ANSUR2, CAESAR, and NHANES studies. Although there might be training differences among the studies, there is no way they could account for the vast differences seen in the means. The Martin et al. (1975) study, present LEO study, ANSUR2, CAESAR,

and NHANES all used standardized anthropometers, calipers, and steel tape measures for the traditional anthropometry measurements. The measurement protocols, including landmarks, dimension definitions (for the comparable dimensions), and data collection procedures are the same. They all used preset intra- and inter-measurer errors as a benchmark for training before data collection. It is well known that anthropometric differences are associated with sex, race/ethnicity, and age. The race/ethnicity and age compositions at different time of these studies can be a confounding source of the differences in these anthropometry measurements. Occupational factors (e.g., self-selection, job effect) also very likely affect the anthropometric variables among occupational groups. Some occupational groups have been identified to have unique anthropometry (Hsiao et al., 2002). The present study reaffirms that LEO could be one of the groups. A new larger-scale LEO anthropometry study with a sufficient sample size by sex, race/ethnicity, and age would allow us to conduct sex- race/ethnicity-, and age-adjusted comparisons to further address the question on confounding factors.

As noted in the Data Analysis section, the CAESAR project measured the “waist circumference” at the “preferred” waist location for its application in clothing, and thus is not comparable to that of other anthropometry databases, such as ANSUR 2, NHANES, LEOs in this study, and LEOs in Martin’s study, which used the omphalion as the reference point. Data users and equipment designers need to be aware of this critical difference in measurement description for the waist circumference in the CAESAR dataset. Also, as noted in the “Differences Among Existing Anthropometry Sources and This LEO Dataset” subsection, LEOs have a well-built upper torso but not belly as compared with the general civilian population in the NHANES data; the negative difference of 60 mm in “waist front length—sitting” (including belly) comparing to CAESAR demonstrates that LEOs on average do not have larger bellies.

Only a very few anthropometry studies have included both nude and in-gear conditions (referred as encumbered anthropometry) in the data collection. Encumbered anthropometry

data allow a quantitative assessment of the additional size and bulk added by the uniform and accompanying gear, which are valuable for workspace design, such as vehicle cab configuration, seatbelt arrangement, and egress layout. The information can also be helpful for other ergonomic assessments, such as computerized biomechanical and physiological analyses on equipment load effect on workers. This study collected five pairs of encumbered anthropometric measurements. The mean values show an increase of 11 mm in bideltoid breadth, 106 mm in hip breadth (sitting), 14 mm in stature (i.e., shoe height), 12 mm in waist breadth (sitting), and 10 kg in weight, which are handy for LEO vehicle space planning, seat design, and computerized digital human modeling for egress and workspace arrangements. Duty belts were ranked the highest discomfort element within patrol duties (Cardoso et al., 2017). The 106-mm increase in hip breadth (sitting) associated with duty belts particularly would have a negative impact on LEOs in entering/exiting vehicles and utilizing vehicle workspace. A Dutch study on “vehicle as workplace” reported that LEOs with body weight of 100 kg and above have had serious ingress/egress issues with their vehicles due to the gear worn and their large body dimensions. In addition, some officers had to cut out vehicle mid-console so they could fit themselves in the vehicle while wearing their duty belt and weapon (Molenbroek et al., 2009). Finally, it would be desirable to add chest breadth and chest depth encumbered measurements in the future large-scale national studies for vehicle space planning, seatbelt design, and ingress/egress arrangement purposes.

Traditional anthropometric calipers and tape measures have been used in anthropometric data collection for studying nutritional status, protective equipment design, and medical and scientific investigations for centuries (Hrdlicka, 1920). In the 1990s, 3D whole-body scanners became commercially available for anthropometry studies for their time efficiency in obtaining human full body dimensions and shapes in a few seconds for each participant (Hsiao et al., 2003) as compared with 60 min in a typical traditional study for 40 dimensions (Hsiao et al., 2014). The present study shows important

shape differences of LEOs at various degrees when compared with other data sources. Specifically, a larger chest is seen in LEOs as compared with waist and hip. This multivariate shape difference might better be captured in a 3D scan. In addition, 3D scans offer opportunities for other product design applications, where ad hoc anthropometric dimensions can be extracted even after an anthropometry survey is completed.

CONCLUSION

Comparing the LEO anthropometric measurements in the present study with the best available data of 45 years ago, we found an increase of 13.6 kg in mean body weight, 103 mm in chest circumference, 122 mm in waist circumference, 26 mm in shoulder breadth, and 4.3 in body mass index. The results along with no change in LEO body height suggest a significant evolution of LEO body shape over the past four decades. In comparisons with military and general population anthropometry (ANSUR2, CAESAR, and NHANES), LEOs in the current study have larger body weight and stature. Army personnel are on average skinnier than LEOs. The general civilian populations are in general less muscular than LEOs. The difference of 101 mm in chest circumference (LEOs vs. CAESAR), 13.7 kg in weight (LEOs vs. CAESAR), 12 mm in waist circumference (LEOs vs. NHANES; statistically insignificant), and -60 mm in “waist front length—sitting (including belly)” (LEOs vs. CAESAR) demonstrate that LEOs are physically bigger than the general population and have a well-built upper torso but not necessarily a larger belly. It would be inadequate to use ANSUR2, CAESAR, and NHANES data for LEO equipment design. A larger-scale LEO anthropometry survey is urgently needed for safe LEO vehicle and PPE design applications.

Encumbered anthropometry data allow an assessment of the additional dimensions added by the uniform and accompanying gear over the nude measurements. This study collected five pairs of measurements, which will be useful for computerized simulations for LEO vehicle cab space configuration, ingress/egress

arrangement, and other ergonomic applications. The differences of 106 mm in hip breadth (sitting) and 10 kg in body weight are particularly notable. The study sets a foundation for a larger scale encumbered anthropometry study of LEOs.

This study showed multivariate size-and-shape differences of LEOs as compared with army and civilian populations. These size-and-shape differences might better be captured in 3D scans. With the maturity of 3D scanning technology, it is desirable that a 3D scanner be used for large-scale national LEO anthropometry surveys to better capture LEO body size and shape. Moreover, anthropometry of female LEOs is still lacking, and the changes in race/ethnicity and age distributions are evolving in the LEO workforce. A large-scale LEO anthropometry study with a sufficient and representing sample size by sex, race/ethnicity, and age is needed.

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KEY POINTS

- The exploratory study showed that law enforcement officer (LEO) body dimensions have changed substantially over the past four decades with no change in stature; a larger scale national LEO anthropometry survey is warranted for

updated data for safe LEO vehicle and PPE design.

- LEOs are physically bigger than army personnel. They also have a notable upper-torso built as compared with the general population. Existing anthropometry datasets of army soldiers and civilian populations would not be suitable for LEO equipment design.
- The magnitudes of difference in some LEO dimensions measured over clothing and with gear as compared with nude measurements are considerable: 106 mm in hip breadth (sitting) and 10 kg in body weight. The information is important for LEO cruiser cab space and ingress/egress modeling.
- Anthropometry of female LEOs, 3D scans of LEOs that catch LEO body size and shape, and a dataset that represents sex, race/ethnicity, and age distributions of current LEO workforce were lacking. Based on the results of this exploratory research, NIOSH initiated a national LEO anthropometry survey in 2018 collecting anthropometry data from 974 LEOs (756 men and 218 women) in 12 different U.S. regions. Data collection using a 3D scanning technology was completed in 2020, with results expected to be available in 2022.

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