HHS Public Access
Author manuscript
Hum Factors. Author manuscript; available in PMC 2024 May 01.

Published in final edited form as:
Hum Factors. 2023 May ; 65(3): 403–418. doi:10.1177/00187208211019157.

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

Hongwei Hsiao[1,*], **Richard Whisler**[1], **Bruce Bradtmiller**[2]

[1]National Institute for Occupational Safety and Health, Morgantown, WV

[2]Anthrotech, Yellow Spring, OH

Abstract

Objectives: This research evaluated measurement errors (ME) of anthropometric devices and measurers (Study I) and anthropometric changes of law enforcement officers (LEO) in 4 decades via a preliminary investigation (Study II), to determine the need for a national LEO anthropometry survey.

Background: Managing measurer-and-equipment ME and defining the necessities of a survey are critical steps for conducting a successful national anthropometry study.

Method: In Study I, 480 datasets (5 measurers × 6 manikins × 16 body dimensions) were recorded, using anthropometric calipers and tapes, two full-body three-dimensional scanners, and a wireless digital tape. In Study II, 32 body dimensions of 67 regional male LEOs were measured and the data were compared to the best available LEO anthropometry data from 1975 and two recent non-LEO national anthropometry databases.

Results: Study I showed that MEs of our measurers/equipment were largely within acceptable ranges, and the measurements were generally compatible among traditional caliper/tape, scanner, and digital tape methods. Study II showed that anthropometric dimensions were significantly different between this LEO study and existing data sources.

Conclusion: The results validated that the MEs of measurers/equipment were within acceptable limits. The study confirmed that the existing 45-year-old LEO dataset and recent Army and civilian datasets would not be adequate for armor and equipment design for the current LEO population.

Application: The study results are useful for supporting a decision on investing in a national LEO anthropometry survey and for equipment manufacturers to be aware of the distinctiveness of LEO anthropometry and measurement errors.

PRÉCIS:

*Author for correspondence: Hongwei Hsiao, Ph.D., Chief of the Protective Technology Branch and Coordinator of the Center for Occupational Robotics Research, National Institute for Occupational Safety and Health, 1095 Willowdale Rd., Morgantown, WV 26505; hxh4@cdc.gov.

DISCLAIMER
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.

This article reported an evaluation of measurement errors of anthropometric equipment and measurers (Study I) and an assessment of anthropometric changes of law enforcement officers (LEO) in 4 decades via a preliminary research (Study II) that determined the needs and procedures for a national LEO anthropometry survey.

Keywords

police; body size; manikin; scanner; measurement error

INTRODUCTION

Approximately 745,000 to 900,000 Law Enforcement Officers (LEOs) serve in the U.S. (U.S. Census Bureau, 2018; National Law Enforcement Officers Memorial Fund, 2017). 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 non-fatal injury incidence rate greater than 400 cases per 10,000 full-time workers in 2011–2015 (Bureau of Labor Statistics, 2016). Of these non-fatal 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 (Stafford et al, 2004; Oron-Gilad et al, 2005; NHTSA, 2011), seat arrangement (Donnelly et al, 2009), patrol vehicle cab and equipment configurations (International Association of Chiefs of Police, 2011; Kun et al, 2004; Jones, Ebert, & Reed, 2015), seatbelt-body-armor interface (Granberg, 2001), and overall patrol car design (Dorn & Brown, 2003; Ludwig, 1970). 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; and 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., gender and race/ethnicity) that have occurred in the past 45 years. While 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.

Establishing any national anthropometry database of a special occupational group can be challenging and costly. Controlling measurement errors (ME) of measurers and equipment and defining the extent and justification for a survey are two critical steps for conducting a successful national study. This paper presented two studies in planning for a national anthropometry survey of law enforcement officers (LEO). Study I evaluated anthropometric measurement errors of three measurement tools/methods: (1) traditional anthropometric calipers and tape measures, (2) three-dimensional (3D) whole-body scanners along with digital measurement extraction software, and (3) a wireless digital tape measure. The study results are useful for (1) selecting the most time and cost efficient tools/methods for large-scale anthropometric surveys, (2) identifying the body dimensions that require attentive practice for consistent results, and (3) helping data collection team members in determining their readiness for data collection (i.e., competence to measure body dimensions within acceptable measurement error ranges). Study II was a preliminary investigation of LEO anthropometry to determine whether anthropometric changes of law enforcement officers (LEO) 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.

STUDY I: Assessment of Precision and Accuracy of Equipment and Measurers

OBJECTIVES

The objectives of this study were to assess intra- and inter-measurer technical errors for a series of anthropometric measurements during the use of (1) traditional anthropometric calipers and tape measures (Figure 1a), (2) three-dimensional (3D) whole-body scanners along with digital measurement extraction software (Figure 1b), and (3) a wireless digital tape measure (Figure 1c). The study also evaluated the differences in measurements among the use of these tools.

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, three-dimensional 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, Bradtmiller, & Whitestone, 2003) as compared to 60 minutes in a typical traditional study for 40 dimensions (Hsiao, Whitestone, Kau, Whisler, Routley, & Wilbur, 2014). In addition, in traditional anthropometric studies, circumference measurements by tape measures show the most error between the observers due to variability in the interpretations of skinfolds (Ulijaszek and Kerr, 1999). Three-dimensional whole-body scanners offered an alternative. On the other hand, compatibility of scanner data extraction outcomes with traditional tape measure results was a topic in discussion among research organizations (Hsiao, 2013). Subsequently, a wireless digital tape measure (Gamma Measuring Tape, Advantech Inc.) was introduced in the 2010s for length and circumference measurements with the intent to reduce transcribe errors as compared to the traditional tape measure method which requires the measurer to measure and read aloud for another person to enter the data in a computer. An organized assessment of the measurement errors of these tools/methods would be beneficial to anthropometry scientists, anthropometry data end-users, and research organizations who invest in anthropometry research.

The assessment of intra- and inter-measurer technical errors was to determine the precision level (amount of error variance or repeatability) of measurers and equipment. The evaluation of measurement differences of the various tools/techniques, as compared to the traditional caliper and tape measure method, was to verify the accuracy (deviation to a true value) of the measurement techniques, laying the groundwork for selecting the most adequate tools/methods for large-scale anthropometric surveys. Both assessments were important for anthropometry studies, and for determining the need for a national anthropometry study of law enforcement officers for patrol vehicle and personal protective equipment (PPE) design applications.

METHODS

Participants—A team of five anthropometry measurers participated in the study. Two of them have more than 18 years of experience in anthropometry data collection. Two are considered intermediate level anthropometry measurers who have participated in two national anthropometry surveys. The fifth participant is considered a novice. Six full-scale manikins (3 male and 3 female) in different body size-and-shape combinations were used in this study (Figure 2). Theses realistic manikins are life-size physical models of human bodies, used for the fitting or displaying of clothes of various special sizes. Sixteen body dimensions of the manikins are described in Table 1. The reported value of each dimension for each manikin is the mean of the dimension taken by the five measurers. Six of the dimensions are height-related dimensions; six are length-related; and four are circumference-related. The Large Female manikin has extra-large upper thighs and the Tall Male manikin has a back-sloped chest. These unique-shaped dimensions are considered the most challenging dimensions for measurers. The 480 combined data sets (5 measurers × 6 manikins × 16 body dimensions), with 3 to 6 repeated measurements for each dataset, represent a wide spectrum of potential variations among samples for an anthropometry study.

Manikins in lieu of living humans were used as practice subjects in this study for several reasons. Manikins do not move or breathe, and their “skin” does not have compressibility characteristics like living humans, which is an advantage for scientists to calibrate measurement devices and their measurement skills, independent from the characteristic variations (such as skinfold differences and breathe disparities) among human participants. In addition, use of manikins was an advantage in this study because we could select individual manikins to represent a range of body shapes and sizes, which is not always possible when recruiting human participants for practice. Moreover, the study allowed the measurers multiple opportunities for practice over a long period of time; use of same living humans was not practical.

It should be noted however that practice with living humans is still desired before a large-scale data collection begins to ensure measurers are able to appropriately guide and handle human participants (especially in palpating certain body components) to minimize potential measurement errors.

Study Procedure—Landmarks corresponding to the sixteen body dimensions described in Table 1 were marked on each of the 6 manikins by an experienced anthropometry staff. The sixteen body dimensions were then measured by the 5 measurers for each dimension, initially for 3 times and then again for 3 times two weeks later using an anthropometer/caliper (GPM, Switzerland) and a steel tape measure (Lufkin Inc., US). In addition, a wireless digital tape measure (Gamma Measuring Tape, Advantech Inc.) was used to measure the 4 circumference-related body dimensions by the 5 measurers for 3 times for each dimension. The six manikins were then scanned by two 3-dimensional full-body scanners (Models WB4 and WBX, Cyberware Inc.). The same abovementioned sixteen body dimensions were extracted three times for each manikin scan from each scanner, using a semi-automated software (Anthroscan, Human Solutions Group). The extractions (semi-automatic) were operated by a 3-dimensional anthropometry expert.

Analyses: Intra-Measurer and Inter-Measurer Errors (Precision)—For intra-measurer measurement error (ME) for a specific body dimension measured by an individual measurer, the calculation can be expressed by the equation below:

$$\mathrm{ME}_{\text{intra-measurer}} = \sqrt{\left(\sum_{1}^{N}\left(\left(\sum_{1}^{J} M^{2}\right) - \left(\left(\sum_{1}^{J} M\right)^{2}/J\right)\right)\right)/N(J-1)}$$

Where N is the number of manikins, J is the number of trials (repetitions) for a variable (dimension) taken on each manikin, and M is the dimension measurement. The unit of ME is the same as the unit of the anthropometric measurement in question.

For inter-measurer ME for a specific body dimension, the calculation can be expressed by the equation below:

$$\mathrm{ME}_{\text{inter-measurer}} = \sqrt{\left(\sum_{1}^{N}\left(\left(\sum_{1}^{k} M^{2}\right) - \left(\left(\sum_{1}^{k} M\right)^{2}/K\right)\right)\right)/N(K-1)}$$

Where N is the number of manikins, K is the number of measurers for a variable (dimension) taken on each manikin, and M is the measurement (in mean value if multiple trials were collected by a measurer).

Analyses: Differences in Measurements among the Equipment/Techniques (Accuracy)—T-tests (Hotelling T^2) were performed to compare the measurement difference between the traditional measurement technique (n = 5 measurers * 6 trials = 30) and 3-dimensional scanning technique (n = 2 scanners * 3 extractions = 6) for each manikin for each of the 16 body dimensions. T-tests (Hotelling T^2) were also performed to compare the measurement difference between the traditional tape measurement technique (n = 30) and digital tape method (n = 5 measurers × 3 trials = 15) for each manikin for each of the 4 circumference-related dimensions.

Allowable Errors—While there is no objective standard on allowable anthropometry measurement errors, some experimental studies have documented the practical reality in measurement deviations (Gordon et al., 1989; Hotzman et al., 2011), which are considered as good as the anthropometry research communities can do and would accept. The practical "allowable errors" of the 16 body dimensions tested in this study, based on Gordon et al. (1989) and Hotzman et al. (2011), are summarized in Table 2.

RESULTS

Intra-measurer and Inter-measurer Errors (Precision)—Table 3a summarizes intra-measurer and inter-measurer measurement errors (5 measurers × 6 manikins) in the use of traditional anthropometric calipers and tape measures. Overall, 3.8% of intra-measurer errors and 6.3% of inter-measurer errors were larger than allowable errors as set by Gordon et al. (1989) and Hotzman et al. (2011). Among these, the range of discrepancies relative to allowable error were 0.1 to 3.1 mm, which have minimal practical implication. Table 3b reports intra-scanner and inter-scanner measurement errors (3D Scanner: 2 scanners × 3 extractions). Overall, 0% of intra-scanner errors and 12.5% of inter-scanner errors (along with dimension extraction software) were larger than allowable errors. These discrepancies were 0.7 to 0.8 mm larger than the allowable errors, which also have minimal practical implication. Table 3c summarizes intra-measurer and inter-measurer errors (5 measurers × 6 manikins) during the use of wireless digital tape. Of these, none was larger than the allowable errors.

Differences in Measurements among the Tools/Techniques (Accuracy)—Table 4a summarizes the differences between traditional caliper/tape (n = 5 measurers × 6 trials = 30) and scanner (n = 2 scanners × 3 extractions = 6) measurements by the matrix of 16 body dimensions × 6 manikins. Thirty-nine out of 96 measurement differences (41%) were statistically significant. Of the 39 differences, 25 were practically small and/or within the allowable error, and 8 were due to measurement definitions (joint-to-joint length in traditional anthropometer measurement vs. curve surface length in the 3D scan extractions) associated with Acromion-Radiale length and Radiale-Stylion length. The major differences between traditional caliper/tape and scanner measurements were associated with thigh circumference and chest depth, in particular for the tall male manikin, which has a distinct concave body shape.

Table 4b summarizes the differences between traditional tape (n = 5 measurers × 6 trials = 30) and wireless digital tape (n = 5 measurers × 3 trials = 15) measurements by the matrix of 4 circumference-related dimensions × 6 manikins. For chest, waist, and hip circumferences, 51% of the measurement differences were statistically significant. However, all of the differences were practically small and/or within the allowable range of errors. For the thigh circumference, the difference was statistically significant for each manikin and the wireless digital tape method produced smaller measurement values of 7.4 mm to 14.4 mm (average 9.5 mm), which are 1.4 mm to 8.4 mm (average 3.5 mm) above the acceptable error of 6 mm.

DISCUSSION

Intra-measurer and Inter-measurer Errors of Measurement (Precision)—The evaluation of measurement errors (ME) of measurers and equipment provided feedback for our NIOSH anthropometry team to fine-tune our measurement skills and determine our readiness for data collection in the field. Table 3a revealed that two trainees (1 novice and 1 semi-expert) had higher intra-measurer errors (3 trials) in Day 1 and improved their results substantially in Day 2 during the use of traditional calipers and tape measures, which demonstrated the importance of practice before field data collection. Table 3b revealed that both 3-dimensional scanners (WB4 and WBX models) along with the dimension extraction software performed very well. The repeatability of the scanners and software as a whole was excellent. Given that only one scanner would be used in the field data collection, the overall technical error of measurement would be small. Table 3c revealed that the precision (repeatability) of the digital tape for circumference-related measurements was excellent and measurers used the tool consistently.

Differences in Measurements among the Equipment/Techniques (Accuracy)— Table 4a revealed that the traditional and scanner methods yielded compatible results for all six height-related dimensions. Scanners can be used to substitute for the traditional anthropometer method to save data collection time in the field. For the six length-related dimensions, software measured the Acromion-Radiale length and Radiale-Stylion length in curvature along the upper arm surface and lower arm surface which are different from the traditional caliper method that measures the shortest distance between two points. A systematic correction is needed for accuracy if the scanner method is used for a national survey. Special care must be made when measuring chest breadth and chest depth for subjects with a muscular and backward sloped chest (in the current case tall and heavy male manikins); traditional caliper and scanner methods returned incompatible results for chest breadth and chest depth for manikins with a muscular and backward sloped chest. For the four circumference-related dimensions, traditional tape and scanner methods produced compatible results for chest, waist, and hip circumferences, except for the tall male manikin which has a muscular and backward-sloped chest. The major differences between traditional tape and scanner measurements were seen in thigh circumference. Scan images tend to have holes at the upper inner thigh area, which are observed in the scans of heavy and tall/large manikins, and the software seems to “predict” the dimension with certain assumptions which yielded larger values (on average 10.7 mm).

Table 4b revealed that the traditional tape and wireless digital tape methods produced compatible results for chest, waist, and hip circumferences. The wireless digital tape can be used to substitute for traditional tapes for these measurements to reduce the potential errors associated with reading and recording data during the use of traditional tapes. For the thigh circumference, the wireless digital tape method produced on average 9.5 mm smaller measurement than the traditional tape method. The relative bulkiness of the wireless digital tape may be a contributing factor. It is somewhat awkward to take this measurement and push the transmission button simultaneously which may have resulted in smaller values due to compression on the thigh.

CONCLUSION (STUDY I)

The assessments of technical errors of measurements (precision) and differences among the measurement techniques (accuracy) are important for anthropometry studies. This study demonstrated that practice improved data collection quality. Chest Depth and Acromion-Radiale Length are dimensions that would benefit from more practice for better precision. Both the scanner and wireless digital tape methods in general have excellent precision. Also, the scanner and traditional caliper/tape methods produced compatible results (accuracy) for height-related dimensions, foot dimensions, and chest, waist, and hip circumferences. Extra care is needed when measuring Chest Breadth and Chest Depth for subjects with a muscular and backward-sloped chest for both methods; these also demonstrate the importance and value of the scanning method in a national anthropometry study as repeated measurements can be done to verify the results once a scan image is available. Moreover, wireless digital tape and traditional tape methods produced compatible results for chest, waist, and hip circumferences. Finally, both scanner and wireless digital tape methods do not produce compatible or consistent results with the traditional tape method for thigh circumference. It is suggested that the traditional tape method be used in national anthropometry surveys along with the scanning method if thigh circumference is required in a survey; it offers an additional opportunity to study and improve this discrepancy. In short, 3-dimensional full body scanning technology and wireless digital tape methods offer an excellent alternative over the traditional caliper/tape method for large-scale anthropometric surveys, with a few minor caveats.

STUDY II: Preliminary Assessment of Anthropometric Changes of Law Enforcement Officers

OBJECTIVE

The objective of this preliminary assessment of LEO anthropometry was to (1) determine whether anthropometric changes of law enforcement officers (LEO) 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 to define the need or extent for a nationwide LEO anthropometry survey

METHODS

Participants—Seventy-four law enforcement officers from West Virginia comprised the measurement sample for this pilot study. The sample included 67 men and 7 women. As the female officers were so few in number in this preliminary study, we are only reporting 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 age 22–34, 21% (14/67) were age

35–44, and 18% (12/67) were age 45–56. 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.

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. An anthropometer/caliper (GPM, Switzerland), two traditional steel tape measures (Lufkin Inc., US), 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-D) full-body scanner (Figure 1b) 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 Study I as a benchmark (Gordon, 1989; Hotzman et al., 2011). A measuring station for the traditional measurements was set up at the NIOSH facility in Morgantown, WV. As each participant arrived, he 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 software algorithms contain a combination of outlier identification and regression techniques, building on existing anthropometry databases. If needed, the measurement can be retaken while the subject is still available.

After the nude dimensions were taken, the participants moved on to the 3-dimensional (3-D) 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, 1975) to be compared were all traditional measurements, this report is concerned only with the traditional measurement data without the 3-D scanning component.

DATA ANALYSIS

Weighted Sampling—Before data were analyzed, a weighting procedure was applied to the samples to ensure that the current sample characterizes the current law enforcement officer population in age composition. There were 744,674 LEOs in 2016 in the U.S. with a distribution of 13.3% females and 86.7% males (U.S. Census Bureau, 2018). Of the LEO occupation, 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 preliminary 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

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

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 U.S. (U.S. Census Bureau, 2018). The weightings would be (222954/580971)/(41/67) = 0.62712 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 Law Enforcement Officers Compared with Three U. S. Anthropometry Data Sources—Law enforcement officers were last measured for their body dimensions in 1975 (Martin, 1975), and designs for vehicles and equipment have been based on those data since that time. This study provides a preliminary opportunity to document whether, and to what extent, the body dimensions of law enforcement officers have changed. We have identified 10 dimensions whose descriptions are the same between the Martin study and the present one. It should be noted that the Martin (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 law enforcement officers 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 pilot study sample to the US civilian population as represented by the Civilian American and European Surface Anthropometry Resource (CAESAR) data set (Harrison and Robinette, 2002). Weighted CAESAR data were used. There are 13 comparable dimensions between the present LEO pilot study and CAESAR. A two-tailed t-test with a p-value of 0.05 as the significance level was performed for each dimension. While a more recent civilian anthropometry data set 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 data set contains only three comparable dimensions (stature, weight, and body mass index) with the present LEO pilot study. The data set would be insufficient to address some unique body characteristics of LEOs, such as chest circumference and bideltoid breadth. The NHANES data thus were not included in this analysis.

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 5. Both unweighted and weighted results are presented.

Current Law Enforcement Officers (LEO) Compared with 1975 LEO Data Source—Table 6 shows the results of t-test comparisons of means between the current and Martin (1975) studies for nude measurements. The Martin dataset of 1975 contained only nude measurements. Eight of the 10 dimensions are different at the two-tail $\alpha = 0.05$ statistical significance level ($p = 0.05/10 = 0.005$ for ten paired comparisons); stature is basically equivalent and sitting height is not statistically different. In every case that is significantly different, the pilot study measurement is larger than the earlier Martin measurement. The differences are especially marked in the torso and are generally related to the 13.6 kg increase in average weight (weighted sample). This result, if confirmed by a larger study, suggests that relying on the Martin data of 1975 for current and future design of law enforcement vehicles and PPE may lead to inaccurate results.

Current Law Enforcement Officers Compared with Army Data Source—Comparisons between current law enforcement officers and Army data source (ANSUR 2 survey; Gordon et al., 2014) at two-tail $\alpha = 0.05$ statistical significance level ($p = 0.05/13 = 0.0038$ for thirteen paired comparisons) are shown in Table 7. Eleven of 13 dimensions are significantly different between ANSUR 2 and the present study. The law enforcement officers are 27 mm taller and 11.4 kg heavier, and are larger on every dimension, except for popliteal height and crotch height. It should be noted that 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. This suggests that the ANSUR 2 data set would be an inappropriate temporary substitute for LEO equipment design applications, especially for body armor and seatbelts.

Current Law Enforcement Officers Compared with U.S. General Population Data Source—There are 13 comparable dimensions between the present LEO pilot study and CAESAR, and ten of the 13 dimensions are significantly different at the two-tail $\alpha = 0.05$ statistical significance level ($p = 0.05/13 = 0.0038$ for thirteen paired comparisons) (Table 7). The largest differences are that the mean waist circumference for LEOs is larger than the CAESAR civilian sample by 129 mm, and the body weight of the LEO sample is larger than the civilian mean by 13.7 kg and the LEO sample is taller by 16 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.

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, i.e., 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, and this study are seen in Table 8. It shows that the 95th percentile values from the law enforcement officer study sample are larger than the earlier Martin study and ANSUR 2 on each of the design dimensions expect for crotch height and popliteal height for the ANSUR 2. They are also larger than those of the CAESAR except for sitting height. It is worth noting that the 95th percentile value of Waist Front Length (including belly) of LEOs is much smaller than that of CAESAR, while the 95th percentile value of Chest Circumference of LEOs is much larger than that of Martin (1975), ANSUR 2, and CAESAR. The differences have significant implications in LEO vehicle and PPE (such as body armor) design.

CONCLUSION (STUDY II)

Compared to the 10 compatible dimensions of LEO anthropometry of 45 years ago, eight dimensions are different at the mean. In addition, 11 out of 13 compatible dimensions between ANSUR 2 and the LEO study are significantly different, and 10 out of 13 comparable dimensions between CAESAR and the LEO study are significantly different. More importantly, the 95th percentile value of Chest Circumference of LEOs in this study is much larger than that of 1975 LEO data, ANSUR 2, and CAESAR, while the 95th percentile value of Waist Front Length (including belly) of LEOs is much smaller than that of CAESAR. These differences suggest that none of the 1975 LEO Anthropometry, ANSUR 2, and CAESAR data sets would be an adequate substitute for current data on U.S. law enforcement personnel. The differences have significant implications in LEO vehicle and PPE (such as body armor) design. A nationwide LEO anthropometry survey is justified and urgently needed for safe LEO vehicle and PPE design applications.

ACKNOWLEDGEMENT

The authors extend their appreciation to the entire research team members and collaborators: Joyce Zwiener, Darlene Weaver, Mahmood Ronaghi, Bradley Newbraugh, Mat Hause, Tony McKenzie, Gene Hill, James Green, and many others who provided technical and administrative support to this research project. The authors are also in debt to many industrial partners, stakeholders, and others who provided keen insight and helpful suggestions to this study.

REFERENCES

Donnelly C, Callaghan J, & Durkin J (2009). The Effect of an Active Lumbar System on the Seating Comfort of Officers in Police Fleet Vehicles. International Journal of Occupational Safety and Ergonomics, 15(3):295–307. [PubMed: 19744371]

Dorn L, & Brown B (2003). Making sense of invulnerability at work - a qualitative study of police drivers. Safety Science, 41:837–859.

Fryar CD, Gu Q, Ogden CL, Flegal KM (2016). Anthropometric reference data for children and adults: United States, 2011–2014. National Center for Health Statistics. Vital Health Stat, 3(39).

Gordon CC, Blackwell CL, Bradtmiller B, Parham JL, Barrientos P, Paquette SP, Corner BD, Carson JM, Venezia JC, Rockwell BM, Mucher M, & Kristensen S (2014). 2010–2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics (NATICK/TR-15–007). Natick, MA: U.S. Army Natick Research, Development, and Engineering Center.

Granberg L (2001). Polisen hedrade bortgången arbetskamrat [The police pay tribute to deceased colleague]. Borås Tidning den 7 juni (in Swedish) as reported in Lundälv et al (2010) How do we reduce the risk of deaths and injuries from incidents involving police cars? Police Practice and Research, 11(5): 437–450.

Harrison C, & Robinette K (2002). CAESAR: Summary Statistics for the Adult Population (Ages 18–65) of the United States of America (AFRL-HE-WP-TR-2002–0170). Wright-Patterson AFB, OH.

Hotzman J, Gordon CC, Bradtmiller B, Corner BD, Mucher M, Kristensen S, Paquette S, and Blackwell C (2011). Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010–2011 (TR-11–017). Natick, MA: U.S. Army Natick Soldier Research, Development, and Engineering Center.

Hrdlicka A (1920). Anthropometry. Philadelphia, PA: The Wistar Institute of Anatomy and Biology.

Hsiao H (2013) Anthropometric procedures for protective equipment sizing and design. Human Factors, 55(1): 6–35. [PubMed: 23516791]

Hsiao H, Bradtmiller B, Whitestone J (2003). Sizing and fit of fall-protection harnesses, Ergonomics, 46(12): 1233–1258. [PubMed: 12933082]

Hsiao H, Whitestone J, Kau TY, Whisler R, Routley JG, and Wilbur M (2014). Sizing firefighters: method and implications. Human Factors, 56 (5): 873–910. [PubMed: 25141595]

International Association of Chiefs of Police (2011). Preventing Traffic-Related Line-of-Duty Death. Alexandria, VA: Author.

Jones M, Ebert S, & Reed M (2015). A Pilot Study of Law Enforcement Officer (LEO) Anthropometry with Applications to Vehicle Design for Safety and Accommodation (UMTRI-2015–21). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute.

Kun LK, Miller WT, & Lenharth WH (2004). Computers in Police Cruisers. Pervasive Computing, Oct–Dec 2004: 34–41.

Ludwig HG (1970). Study of the Police Patrol Vehicle. Washington, D.C.: National Criminal Justice Reference Service, U.S. Department of Justice Law Enforcement Assistance Administration.

Martin J, Sabeh R, Driver L, Lowe T, Hintze R & Peters P (1975). Anthropometry of Law Enforcement Officers (Technical Document 442). San Diego, CA: Law Enforcement Standards Laboratory, National Bureau of Standards.

National Law Enforcement Officers Memorial Fund. (2017). Law enforcement facts. Retrieved from https://nleomf.org/facts-figures/law-enforcement-facts.

NHTSA. (2011). Characteristics of Law Enforcement Officers' Fatalities in Motor Vehicle Crashes (DOT HS 811 411). Washington, DC: National Highway Traffic Safety Administration.

Oron-Gilad T, Szalma JL, Stafford SC, & Hancock PA (2005). Police officers seat belt use while on duty. Transportation Research Part F 8, (2005): 1–18

Stafford SC, Oron-Gilad T, Szalma JL, Delasontos K, & Hancock PA (2004). Attitudes of Police Officers toward Seat Belt Use while on Duty. Proceedings of the Human Factors and Ergonomics Society, 48:131–1135.

Tiesman HM, Swedler DI, Konda S, Pollack KM (2013). Fatal occupational injuries among U.S. law enforcement officers: A comparison of national surveillance systems. American Journal of Industrial Medicine, 56(6): 693–700. [PubMed: 23532837]

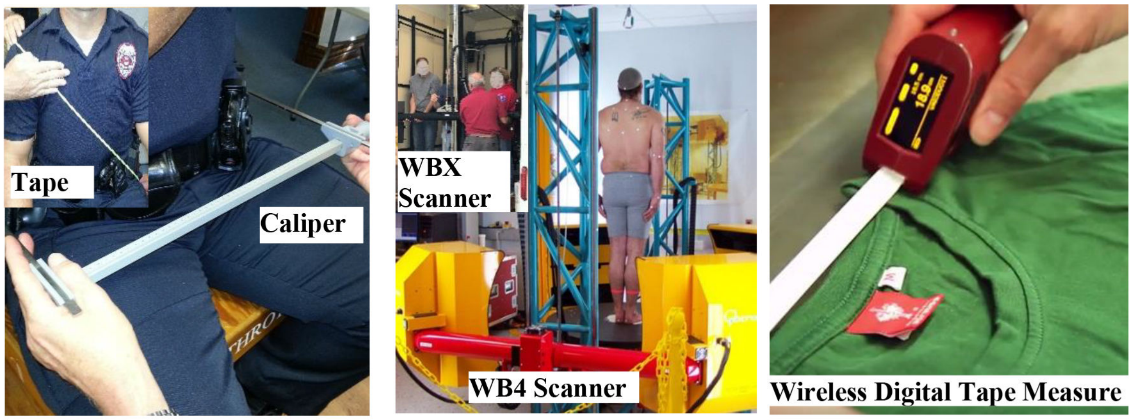
Ulijaszek SJ, & Kerr DA (1999). Anthropometric measurement error and the assessment of nutritional status. British Journal of Nutrition, 82:165–177. [PubMed: 10655963]

U.S. Bureau of Labor Statistics. (2016). Nonfatal Occupational Injuries and Illnesses Requiring Days Away from Work, 2015. Retrieved from https://www.bls.gov/news.release/pdf/osh2.pdf

U.S. Census Bureau. (2018). Data USA: Police Officers. Retrieved from https://datausa.io/profile/soc/333050/.

KEY POINTS (Studies I and II)

1. Both the scanner and wireless digital tape methods in general had excellent precision and produced compatible results with the traditional caliper/tape measurement method, except for thigh circumference. They offer an excellent alternative over the traditional caliper/tape method for large-scale anthropometric surveys for time efficiency, with a few minor caveats.
2. The assessment of measurement errors (precision) of measurers and equipment as well as evaluation of differences (accuracy) among the measurement techniques served the purpose of verifying the readiness of an anthropometry data collection team.
3. Extra care is needed when measuring Chest Breadth and Chest Depth for subjects with a muscular chest for both traditional caliper/tape and 3-dimensional scan extracting methods. Thigh circumference remains the most challenging body dimension to measure accurately.
4. The preliminary study confirmed that a national LEO anthropometry study is warranted; available datasets would not be an adequate substitute for data of current LEOs. Based on the results of this research, NIOSH initiated a national LEO anthropometry survey in 2018 collecting anthropometry data from 974 LEOs in 12 different U.S. regions. Data collection was completed in early 2020, with results expected to be released in 2022.



(1a) (1b) (1c)

Figure 1.

Three data collection tools evaluated in this study: traditional anthropometric tape and caliper (1a), whole-body WBX and WB4 scanners (1b), and a wireless digital tape measure (1c).

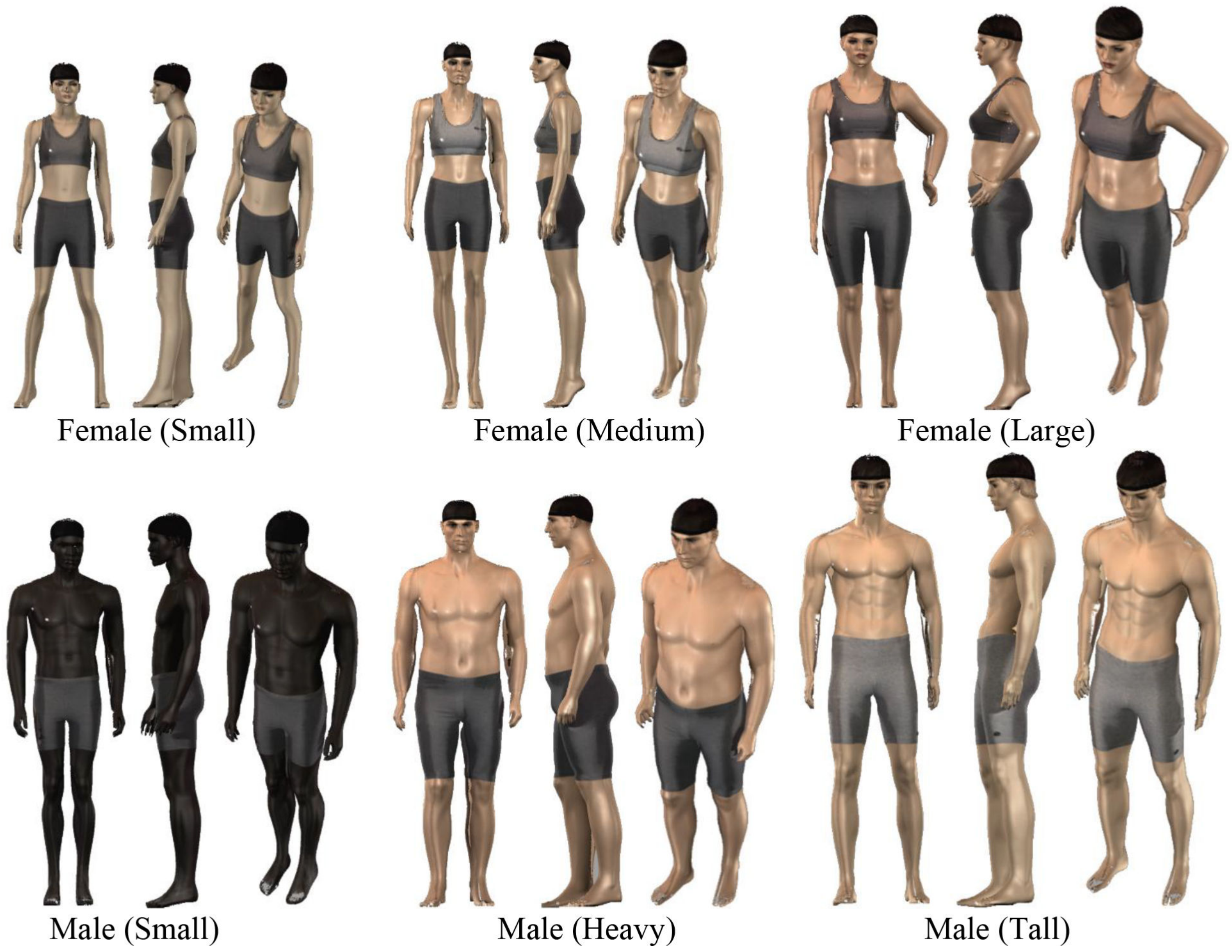


Figure 2.

Six manikins in different body size-and-shape combinations used in the study (in front, side, and perspective views).

Table 1.

Body dimensions (in mm) of the six manikins used in this study

	Variables	Female Small	Female Medium	Female Large	Male Small	Male Heavy	Male Tall
Height*	Stature	1698	1791	1855	1871	1886	1950
	Cervical Height	1452	1557	1585	1597	1652	1667
	Acromial Height	1405	1506	1506	1535	1563	1591
	Axilla Height	1328	1431	1394	1436	1426	1478
	Chest Height	1268	1318	1360	1388	1372	1455
	Crotch Height	811	913	848	894	859	915
Length	Acromion-Radiale Length	265	264	316	259	349	312
	Radiale-Stylion Length	225	258	335	313	256	289
	Chest Breadth	253	267	304	332	374	341
	Chest Depth	210	225	295	238	293	271
	Foot Breadth	72	73	75	79	91	86
	Foot Length	203	215	228	247	253	253
Circumference	Chest Circumference	791	865	1073	978	1122	1045
	Waist Circumference	611	660	862	792	1009	816
	Hip Circumference	820	883	1096	925	1128	993
	Thigh Circumference	478	514	675	550	682	608
Note	Heel above floor*	31	94	78	30	0	21
	"Corrected" stature*	1667	1697	1777	1841	1886	1929
	Percentile of "Corrected" stature**	75th	87th	>99th	87th	95th	>99th

*The 6 body-height-related measurements of manikins were measured from floor with their heel lifted which is different from the standard standing pose in typical anthropometry studies. Their heel heights are reported in the row: "Heel above floor." The "Corrected" stature reflects the stature after the subtraction of the "heel above floor."

**The percentile of "Corrected" stature, based on the Vital Health Statistics (Fryar, 2016), showed that these displaying manikins are relatively tall as compared to real human population.

Table 2.

Practical "allowable error" of the 16 body dimensions tested in this study

References \ Dimensions	Stature (mm)	Cervical Height (mm)	Acromial Height (mm)	Axilla Height (mm)	Chest Height (mm)	Crotch Height (mm)	Acromion-Radiale (mm)	Radiale-Stylion (mm)	Chest Breadth (mm)	Chest Depth (mm)	Foot Breadth (mm)	Foot Length (mm)	Chest Circum (mm)
Gordon	11	7	7	10	11	10	4	6	8	4	2	3	
Hotzman	6	7	7	7	9	10	4	6	7	4	2	3	

Table 3a.

urer Errors using Traditional Anthropometric Calipers and Tape Measures: intra-measurer and inter-measurer errors, (5 measurers × 6 manikins)

urer ience	Trials for each of 6 manikins	Stature (mm)	Cervical Height (mm)	Acromial Height (mm)	Axilla Height (mm)	Chest Height (mm)	Crotch Height (mm)	Acromion-Radiale (mm)	Radiale-Stylion (mm)	Chest Breadth (mm)	Chest Depth (mm)	Foot Breadth (mm)	Foot Length (mm)	Chest Circumference (mm)	Waist Circumference (mm)	Hip Circumference (mm)	Thigh Circumference (mm)
rror t 1	Day 1: 3 trials	2.8	1.6	2.3	1.7	2.5	5.4	**5.2**	2.4	1.6	1.7	0.8	1.4	6.0	3.0	9.3	3.4
	Day 2: 3 trials	2.4	1.4	2.4	2.7	2.6	2.3	1.6	2.1	1.6	1.5	0.7	1.0	5.5	3.4	4.3	2.3
	Total: 6 trials	2.9	1.8	2.8	2.9	2.9	4.2	3.7	2.7	1.9	1.8	0.8	1.5	6.2	3.7	9.1	3.1
rror t 2	Day 1: 3 trials	0.9	1.5	1.2	2.4	2.7	2.7	1.6	1.7	5.7	2.1	0.6	1.4	6.2	5.9	10.2	4.4
	Day 2: 3 trials	2.7	2.1	2.1	3.1	1.7	2.1	1.2	1.1	3.7	3.7	0.9	1.9	5.5	6.4	7.3	3.7
	Total: 6 trials	1.9	2.0	2.1	3.4	3.2	2.6	1.5	1.5	4.8	3.0	1.0	1.7	9.3	6.1	8.6	4.7
rror t 1	Day 1: 3 trials	2.4	**10.1**	1.5	2.4	2.2	3.0	2.2	2.7	4.7	**5.4**	1.3	1.2	5.5	3.3	5.7	1.5
	Day 2: 3 trials	2.0	1.5	1.8	1.6	2.5	1.9	2.8	1.8	3.4	3.2	1.2	2.8	4.7	3.7	5.5	1.5
	Total: 6 trials	3.0	7.0	2.8	2.3	2.9	4.6	3.8	3.5	5.5	**4.9**	1.4	**3.1**	5.4	3.6	5.7	2.1
rror t 2	Day 1: 3 trials	1.2	1.2	1.3	1.5	2.3	3.7	2.1	1.5	1.9	1.8	1.5	2.4	9.6	6.4	11.9	3.5
	Day 2: 3 trials	2.0	3.6	3.3	4.1	2.4	3.2	1.8	2.8	3.0	1.8	**2.1**	**3.2**	8.7	7.0	6.4	3.2
	Total: 6 trials	3.1	4.5	4.4	6.2	4.6	4.0	2.6	2.9	2.5	2.3	1.8	2.9	12.6	6.5	9.4	4.0
rror e 1	Day 1: 3 trials	4.3	2.9	3.2	5.3	3.5	5.4	**5.3**	4.9	3.6	1.5	1.9	0.7	14.7	6.3	9.2	5.6
	Day 2: 3 trials	3.4	3.4	2.1	2.5	2.4	1.4	0.7	1.3	1.6	1.6	0.5	1.0	9.5	8.5	6.9	2.2
	Total: 6 trials	4.6	5.7	3.4	4.6	4.3	**10.8**	**5.3**	3.6	3.8	2.7	1.3	1.0	**17.8**	6.9	10.3	4.5
rror	Means: 6 trials	1.7	2.1	2.6	2.9	2.3	2.4	3.3	2.8	6.2	**6.3**	2.1	2.6	8.5	6.1	7.5	3.8

urer ience	Trials for each of 6 manikins	Stature (mm)	Cervical Height (mm)	Acromial Height (mm)	Axilla Height (mm)	Chest Height (mm)	Crotch Height (mm)	Acromion-Radiale (mm)	Radiale-Stylion (mm)	Chest Breadth (mm)	Chest Depth (mm)	Foot Breadth (mm)	Foot Length (mm)	Chest Circumference (mm)	Waist Circumference (mm)	Hip Circumference (mm)	Thigh Circumference (mm)
able	Gordon, 1989	11	7	7	10	11	10	4	6	8	4	2	3	15	12	14	6
	Hotzman, 2011	6	7	7	7	9	10	4	6	7	4	2	3	14	12	--	6

arger than allowable error: 3.8% (6/160 [5 measurers × 2 days × 16 dimensions] = 3.8%) of intra measurer errors and 6.3% (1/16 [16 dimensions] = 6.3%) of inter-measurer errors were larger than le errors.

Table 3b.

' and Data Extraction Software Errors: Intra-scanner and inter-scanner errors (3D Scanner: 2 scanners × 3 extractions)

er nce	Extractions for each of 6 manikins	Stature (mm)	Cervical Height (mm)	Acromial Height (mm)	Axilla Height (mm)	Chest Height (mm)	Crotch Height (mm)	Acromion-Radiale (mm)	Radiale-Stylion (mm)	Chest Breadth (mm)	Chest Depth (mm)	Foot Breadth (mm)	Foot Length (mm)	Chest Circumference (mm)	Waist Circumference (mm)	Hip Circumference (mm)	Thigh Circumference (mm)
or 1	Scanner WB4 (3 extractions)	2.0	1.7	1.7	0.7	1.1	1.6	2.8	1.9	4.1	1.1	1.2	1.8	1.7	3.2	12.4	2.4
or 2	Scanner WBX (3 extractions)	1.1	0.7	0.6	1.0	1.4	1.2	2.1	1.5	3.6	1.8	0.5	0.5	1.8	1.3	1.0	6.0
or rs	Means: 3 extractions	4.9	2.2	3.5	2.6	2.1	6.7	1.7	2.7	3.8	2.0	**2.7**	2.7	4.0	4.1	8.9	**6.8**
le	Gordon, 1989	11	7	7	10	11	10	4	6	8	4	2	3	15	12	14	6
	Hotzman, 2011	6	7	7	7	9	10	4	6	7	4	2	3	14	12	--	6

ger than allowable error: 0% (0/32 [2 canners × 16 dimensions] = 0%) of intra scanner errors and 12.5% (2/16 [16 dimensions] = 12.5%) of inter-scanner errors (along with dimension extraction
were larger than allowable errors.

Table 3c.

Wireless Digital Tape Measurement Errors for Circumference Measurements: intra-measurer and inter-measurer errors (Digital Tape: 3 extractions)

Measurer Experience	Extractions for each of 6 manikins	Chest Circumference (mm)	Waist Circumference (mm)	Hip Circumference (mm)	Thigh Circumference (mm)
Intra error: Expert 1	3 extractions	3.7	3.8	4.8	2.3
Intra error: Expert 2	3 extractions	4.6	6.2	7.7	2.6
Intra error: Semi Expert 1	3 extractions	7.4	7.9	12.1	2.8
Intra error: Semi Expert 2	3 extractions	6.9	3.6	4.2	3.4
Intra error: Novice 1	3 extractions	8.5	8.0	8.7	3.2
Inter error: 5 measurers	Means: 3 extractions	9.2	6.9	7.8	4.3
Allowable Error	Gordon et al., 1989	15	12	14	6
	Hotzman et al., 2011	14	12	N/A	6

Bold: Larger than allowable error: 0% (0/20 [5 measurers × 4 dimensions] = 0%) intra measurer errors and 0% (0/4 [4 dimensions] = 0%) of inter-measurer errors were larger than allowable errors.

Table 4a.

s between traditional caliper/tape (n= 5 measurers × 6 trials = 30) and scanner (n= 2 scanners × 3 extractions = 6) measurements

	Manikin	Stature (mm)	Cervical Height (mm)	Acromial Height (mm)	Axilla Height (mm)	Chest Height (mm)	Crotch Height (mm)	Acromion-Radiale (mm)	Radiale-Stylion (mm)	Chest Breadth (mm)	Chest Depth (mm)	Foot Breadth (mm)	Foot Length (mm)	Chest Circumference (mm)	Waist Circumference (mm)	Hip Circumference (mm)	Thigh Circumference (mm)
t	Small Female	0.7	−0.1	1.1 *	3.3	2.5	−2.1	**−11.7**	−3.5 *	−1.1 *	−0.7	−0.5 *	−1.6	−14.8	1.1 *	−0.1	−4.5 *
t	Medium Female	−2.0	−2.6	−1.5	−2.0	−0.5	−3.1	**−7.8** *	−5.3 *	−2.3 *	2.8 *	−3.0 *	−1.5	6.7 *	−11.8 *	0.0	**−21.7** *
	Large Female	0.4	−2.3	−1.5	−0.8	0.2	5.1	**−12.9** *	−5.5 *	−2.5	−1.0	−1.0	−2.1	−12.7 *	−1.9	−3.8	**12.3** *
	Small Male	2.9 *	−0.3	3.2 *	2.2	5.2 *	−4.3 *	**−5.4** *	**−12.6** *	0.4	3.5	−1.5	1.2	−13.1 *	4.0	0.9	1.2
	Medium Male	3.3 *	1.9	3.4 *	0.6	5.3 *	−4.5	**−13.8** *	**−6.8** *	0.6	**10.6** *	1.0	−0.6	−7.7	−5.3	5.1	**−21.8** *
	Large Male	−1.7	−4.5 *	−0.5	−1.3	0.0	0.9	**−12.7** *	**−6.2** *	**−10.8**	**13.9** *	−1.6	1.1	**−16.3** *	−4.7	7.0 *	**−29.7** *
	Average	0.6	−1.3	0.7	0.3	2.1	−1.3	**−10.7**	**−6.7**	−2.6	**4.8**	−1.1	−0.6	−9.7	−3.1	1.5	**−10.7**
	Gordon	11	7	7	10	11	10	4	6	8	4	2	3	15	12	14	6
	Hotzman	[illegible]	7	7	7	9	10	4	6	7	4	2	3	14	12	N/A	6
								Software measured the dimension in curve	Software measured the dimension in curve	Large male manikin has a backward sloped back	Large male manikin has a backward sloped back			Large male manikin has a unique chest shape			Scan images have holes. Software predicted dimension

different between traditional and scanner measurements

han allowable error

Table 4b.

Differences in measurements between traditional tape measure (n = 5 measurers × 6 trials = 30) and wireless digital tape measure (n = 5 measurers × 3 trials = 15)

	Manikin	Chest Circumference (mm)	Waist Circumference (mm)	Hip Circumference (mm)	Thigh Circumference (mm)
Traditional measurement minus digital tape measurement (5 measurers)	Small Female	1.7	5.0*	3.1	**8.2***
	Medium Female	7.9*	10.3*	−1.7	**7.4***
	Large Female	10.2*	7.0*	−8.4*	**14.4***
	Small Male	2.7	4.7*	−0.4	**9.1***
	Medium Male	7.0	9.9*	−2.6	**8.7***
	Large Male	9.0*	0.6	−6.4*	**9.3***
	Average	6.4	6.3	−2.7	**9.5**
Allowable Error	Gordon, 1989	15	12	14	6
	Hotzman, 2011	14	12	--	6

*: Statistically different between traditional tape and digital tape measurements

Bold: Larger than allowable error

Table 5.

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
Measured with Gear	Weight, (kg), gear	67	105.9	16	1.95	92	106.9	16	1.6
	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

Table 6.

Summary statistics of the pilot study of law enforcement officers compared to 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 Mean
*Body Mass Index	Martin 1975	2989	26.2	3.3	0.1
	NIOSH-LEO (weighted)	92	30.5	4.4	0.5
*Buttock-Knee Length	Martin 1975	2988	615	27	0.5
	NIOSH-LEO (weighted)	92	629	25	2.6
*Chest Circumference	Martin 1975	2990	1022	79	1.4
	NIOSH-LEO (weighted)	92	1125	100	10.4
*Head Circumference	Martin 1975	2985	575	16	0.3
	NIOSH-LEO (weighted)	92	581	17	1.8
*Knee Height, Sitting	Martin 1975	2984	559	25	0.5
	NIOSH-LEO (weighted)	92	579	25	2.6
*Shoulder Breadth (Bideltoid)	Martin 1975	2985	495	29	0.5
	NIOSH-LEO (weighted)	92	521	32	3.3
‡Sitting Height	Martin 1975	2993	922	34	0.6
	NIOSH-LEO (weighted)	92	929	33	3.4
‡Stature	Martin 1975	2989	1781	58	1.0
	NIOSH-LEO (weighted)	92	1783	67	6.9
*Waist Circumference	Martin 1975	2988	905	94	1.7
	NIOSH-LEO (weighted)	92	1027	113	11.8
*Weight (kg)	Martin 1975	2991	83.3	11.9	0.2
	NIOSH-LEO (weighted)	92	96.9	15.4	1.6

* indicates significantly different from each other (2-tail t-test at significance level of 0.05 with p = 0.05/10 = 0.005 for ten paired comparisons),

‡ indicates no significant difference from each other

Author Manuscript
Author Manuscript
Author Manuscript

Table 7.

Summary statistics of the pilot study of male law enforcement officers (LEO) compared to ANSUR II males and CAESAR males (weight in kg, all other values in mm)

Dimension	Survey	N	Mean	Std Dev	Std Error
Bideltoid Breadth	ANSUR2 *	4082	510	33	.5
	NIOSH-LEO (weighted)	92	521	32	3.3
	CAESAR *	1119	490	38	1.1
Buttock-Knee Length	ANSUR2 *	4082	618	31	.5
	NIOSH-LEO (weighted)	92	629	25	2.6
	CAESAR *	1119	614	36	1.1
Chest Circumference	ANSUR2 *	4082	1059	87	1.4
	NIOSH-LEO (weighted)	92	1125	100	10.4
	CAESAR *	1119	1024	113	3.4
Crotch Height	ANSUR2 ‡	4082	846	47	.7
	NIOSH-LEO (weighted)	92	859	46	4.8
	CAESAR *	1119	797	55	1.6
Head Circumference	ANSUR2 *	4082	574	16	.3
	NIOSH-LEO (weighted)	92	581	17	1.8
	CAESAR ‡	1119	577	18	0.5
Hip Breadth, Sitting	ANSUR2 *	4082	379	30	.5
	NIOSH-LEO (weighted)	92	390	28	3.0
	CAESAR *	1117	376	38	1.1
*Knee Height, Sitting	ANSUR2 *	4082	554	28	.4
	NIOSH-LEO (weighted)	92	579	25	2.6
	CAESAR *	1114	493	31	0.9
Popliteal Height	ANSUR2 ‡	4082	430	25	.3
	NIOSH-LEO (weighted)	90	427	22	2.3
Sitting Height	ANSUR2 *	4082	918	36	.6
	NIOSH-LEO (weighted)	92	929	33	3.4
	CAESAR ‡	1119	921	43	1.3
Dimension	**Survey**	**N**	**Mean**	**Std Dev**	**Std Error**
Stature	ANSUR2 *	4082	1756	69	1.1
	NIOSH-LEO (weighted)	92	1783	67	6.9
	CAESAR ‡	1119	1767	76	2.3
Waist Circumference	ANSUR2 *	4082	941	112	1.8
	NIOSH-LEO (weighted)	92	1027	113	11.8

Dimension	Survey	N	Mean	Std Dev	Std Error
	CAESAR *	1118	895	126	3.8
Waist Front Length, Sitting	ANSUR2 *	4082	388	29	.5
	NIOSH-LEO (weighted)	92	402	29	3.0
	CAESAR *	1119	462	53	1.6
Weight (Kg)	ANSUR2 *	4082	85.5	14.2	.2
	NIOSH-LEO (weighted)	92	96.9	15.4	1.6
	CAESAR *	1119	83.2	17.4	0.5
Hip Circumference	NIOSH-LEO (weighted)	92	1076	75	7.8
	CAESAR *	1119	1032	98	2.9

* indicates significantly different from each other (2-tail t-test at significance level of 0.05 with $p = 0.05/13 = 0.0038$ for thirteen paired comparisons),

≠ indicates no significant difference from each other

Table 8.

95TH percentile design values for law enforcement officers compared to Martin et al. (1975), ANSUR 2, and CAESAR: males (weight in kg, all other values in mm)

Dimension (95th Percentile)	Martin (n=2985)	ANSUR 2 (n=4082)	CAESAR (n=1119)	LEO (n=67) unweighted	LEO (n=92) weighted
Buttock-Knee Length	662	669	673	675	670
Chest Circumference	1158	1207	1210	1280	1290
Head Circumference	601	601	604	608	609
Knee Height, Sitting	602	602	607	622	620
Shoulder (Bideltoid) Breadth	544	567	550	571	574
Sitting Height	979	977	985	987	983
Waist Circumference	1073	1131	1114	1211	1213
Stature	1879	1870	1901	1901	1893
Weight (kg)	104.4	110.7	114.6	122.2	121.6
Crotch Height	--	925	880	926	922
Hip Breadth, Sitting	--	431	435	439	436
Popliteal Height	--	471	--	464	463
Waist Front Length, Sitting	--	438	548	449	450
Hip Circumference	--	1149	1194	1204	1199