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Digital Modeling of Law Enforcement Officers: Progress and Challenges

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Abstract. Over several decades, police officer body dimensions have increased as have the body dimensions of many Americans. But the external dimensions of a law enforcement officer completely outfitted in all of his or her gear has increased dramatically, with the near-constant use of body armor and the addition of body cameras, radios and a host of other work-related items. At the same time, the available space in his or her police cruiser has decreased, with the addition of dash cameras, radios, and computers and the modernization of the bucket seat design. The result is a disaccommodation problem that is increasing with each addition of new equipment for either the officer or the vehicle.

Digital human modeling is an ideal tool to help solve this accommodation problem, by creating realistic models of officers wearing their gear. To create a database for use in that modeling, we recruited approximately 1000 officers from 12 locations around the US and obtained whole body, head, hand, and foot scans from each. In addition, we measured them for a series of traditional anthropometric dimensions both semi-nude and fully equipped in their uniform, body armor and gear. The differences obtained between the equipped and semi-nude officers will allow the verification of future models. Further, we collected data on the vehicles they use, any difficulties with their current vehicles, and the ancillary equipment worn on the body. This paper presents partial results of that study.

The significant challenge going forward will be to create models that take into account the wide diversity in how officers wear their equipment on the body. For example, many officers carry a weapon on the duty belt; some carry it in a thigh holster. Some officers carry a radio on the shirt; others carry it on the duty belt, sometimes in front, and sometimes on the side. We conclude with a suggestion that modelers use data from this survey to accommodate the variability added by the equipment.

Keywords. Anthropometry, Law Enforcement Officer, Vehicle Accommodation

1. Introduction

Anthropometric disaccommodation can affect the ability of any working individual to function safely while carrying out his or her task. For law enforcement officers (LEOs), necessarily encumbered by a considerable amount of bulky equipment, the problem can become critical. And, while anthropometric data are not themselves a solution to

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problems of design and accommodation, the lack of appropriate data is a major stumbling block to improving the design of equipment and LEO workspaces.

In 1975, the US National Bureau of Standards funded a study of the nation's male law enforcement officers [1]. Some 23 dimensions were measured on a large sample (approximately 3000) and they were collected in 17 regions throughout the country. For many years, those were the only data available on which to design police vehicles and protective equipment. It is not known whether, or how often, those data were actually used in design. More recently, designers and engineers have become much more accustomed using anthropometric data in design. But by the time designers began to routinely use anthropometric data, the available data for the nation's police force was woefully out of date. The US police force in 1975 bears little resemblance to today's diverse force that contains female as well as male officers.

In 2014, recognizing the workplace mis-match between officers' physical characteristics and their mobile workplaces, the National Institute for Occupational Safety and Health (NIOSH) funded a pilot study to determine the magnitude of the differences between the force of the 1970s and the then-current force 45 years later. That study [2] identified a number of physical changes, but also started to document the tremendous variability in the equipment that officers routinely wore while on duty. The results were striking enough that NIOSH funded a larger nationwide study. Preliminary work began in 2017 and data collection occurred in 2018 and 2019. The complete documentation of the recent study is still underway, and the results have not been reviewed. This paper, addressed to the digital human modeling community, focuses on the aspects of the study that may have the greatest immediate impact for those modeling officers in their vehicles.

2. Methods

A nationwide sampling plan was developed to capture the demographic variability in today's force. Using US Census data from the most recent census, goals were established for racial/ethnic groups, and an appropriate age distribution for each of four regions in the US. The overall goal was 1000 officers. Female officers account for only 17.6% of the US force, so a proportional sampling by sex would not have provided statistical power for decision-making. The female sample was therefore increased to 300 of the 1000 targeted. Male and female data will be reported separately in the final report so the over-representation of females in the sample will not adversely influence the final summary statistics. The sample was collected at 12 police facilities spread over the 4 geographic regions.

A dimension list was created to allow comparison with the earlier Martin et al. study [1], but was also based on experience at NIOSH and Anthrotech in using anthropometric dimensions for vehicle design. In a departure from the Martin study, officers were also measured in their full uniform, including any gear and ancillary equipment that they typically wear while on patrol duty in their car. As police departments in the United States are locally controlled, they vary considerably in what specific equipment constitutes "gear" that officers may wear. We specifically collected information on what items were worn on the duty belt (see below), but additional items of gear that could affect the overall amount of space needed include body armor, body camera, leg holster, leg pads and helmets.

Many of the dimensions are seated dimensions. These were measured in a standard anthropometric sitting posture to allow comparison with earlier datasets, and to minimize the effect of posture on the anthropometric dimensions. At the same time, we acknowledge that anthropometric sitting is not a posture used while driving a vehicle. There is a considerable body of research on automotive seating generally (e.g. [3], [4]) and on driver comfort in police vehicles more specifically [5], [6], [7]. Those issues are not addressed in this paper.

Table 1 shows the dimension list for the lightly clothed (semi-nude measurements as well as the measurements taken over full gear. Dimensions marked with an asterisk are those taken both with gear and without gear.

Table 1. Dimension List.

	Semi-nude		**Over Gear**
*	Bideltoid Breadth, Sitting		Abdominal Extension Depth, Gear, Sitting
	Buttock Height		Acromion-Troch Surface Length, Gear, Sitting
	Buttock-Knee Length	*	Bideltoid Breadth, Gear, Sitting
	Buttock-Popliteal Length		Bi-trochanter Surface Length, Gear, Sitting
*	Chest Breadth		Boot Breadth
	Chest Circumference		Boot Length
*	Chest Depth		Buttock-Shoetip Length, Gear, Sitting
	Crotch Height	*	Chest Depth, Gear
	Elbow Rest Height	*	Chest Width, Gear
	Eye Height, Sitting	*	Hip Breadth, Gear, Sitting
	Foot Breadth, Horizontal		Shoulder-Grip Length, Gear, Sitting
	Foot Length	*	Stature, footwear
	Front Waist Length, Sitting		Thigh Clearance, Gear, Sitting
	Grip Strength, Sitting (kg)	*	Waist Breadth, Gear, Sitting
	Hand Breadth	*	Weight, Gear, kg
	Hand Length		
	Head Arc Length		
	Head Breadth		
	Head Circumference		
	Head Length		
*	Hip Breadth, Sitting		
	Hip Circumference		
	Knee Height, Sitting		
	Nuchale Height, Sitting		
	Popliteal Height		
	Sitting Height		
*	Stature		
	Thigh Circumference		
	Thumbtip Reach		
*	Waist Breadth, Sitting		
	Waist Breadth Height, Sitting		
	Waist Circumference		
	Waist Height		
*	Weight, kg		

In addition to the traditional measurements, 3D scans were taken of the officers while dressed in Spandex scanwear. Scans were taken of the whole body, the head, the foot, and the hand. There is an incomplete consensus in the scanning community about the most useful position for whole body scans (e.g. [8]). This is in part because different scanning technologies impose differing requirements in order to capture data from the axillary and crotch regions. In this case, we used the body position protocol described in the ANSUR and CAESAR surveys [9], [10]. The data from the scans will not be included in the survey documentation, but the scans themselves will form a valuable resource for future researchers as well as those designing officers' protective equipment and vehicles.

The study was reviewed and approved by the NIOSH Institutional Review Board, as well as the Office of Management and Budget. A collaborative team of Anthrotech and NIOSH researchers visited each of the sites to collect the data.

3. Results

The team met and exceeded the goal for male officers, and while the female goal was not met, it does exceed the actual representation of female officers in police forces across the country. Table 2 shows the distribution of race/ethnic group and age group by gender.

Table 2. Race/Ethnic Group, Age Group by Gender.

		Race/Ethnicity			
Gender	Age Group	White	African-American	Hispanic/ Other	Total
Male	18 - 34	182	30	54	266
	35 - 44	186	30	36	252
	≥ 45	175	34	29	238
	Total	543	94	119	756
Female	18 – 34	51	12	22	85
	35 – 44	62	9	12	83
	≥ 45	29	10	11	50
	Total	142	31	45	218
Total	18 – 34	233	42	76	351
	35 – 44	248	39	48	335
	≥ 45	204	44	40	288
	Total	685	125	164	974

The remaining tables show data that are weighted to account for small mis-matches between the final sample demographics and the 2019 estimates from the US Bureau of Labor Statistics for police race and ethnicity [11].

The full results of the survey will be released when the report is complete, as noted above. However, a preliminary look at the comparably measured dimensions between the current study and the Martin study of 1975 [1] show significant differences in a number of dimensions. Specifically, all the dimensions associated with weight gain, such as breadths, depths, and circumferences, show increases (Table 3). The dimensions that did not show an increase were Thumbtip Reach, Stature, and hand. These differences generally match those seen when comparing the Army's ANSUR survey with ANSUR 2, which took place a quarter-century later [12], [10]. Welch's *t* is used for significance testing rather than the common Student's *t* since the variances could not be assumed to be similar between the two studies.

Table 3. Means Test Comparing NIOSH 2020 and Martin 1975 [1]: Males (weight in kg, all other values in mm).

	NIOSH 2020			Martin 1975			Welch's test		
	N	Mean	Std. Deviation	N	Mean	Std. Deviation	Mean Diff.	t	
Bideltoid Breadth, Sit	754	514.1	32.56	2985	494.7	29.42	19.34	14.85	*
Buttock-Knee Length	754	630.9	34.29	2988	615.0	27.11	15.85	11.80	*
Chest Breadth	754	372.5	35.54	2984	346.4	26.35	26.03	18.85	*
Chest Circumference	754	1111.8	100.96	2990	1021.6	78.99	90.20	22.84	*
Front Waist Length, Sit	754	409.4	30.56	2983	413.3	26.91	-3.85	-3.17	*
Hand Breadth	754	90.0	4.65	2987	89.9	4.24	0.08	0.43	
Hand Length	754	193.5	9.93	2989	193.5	9.12	0.04	0.10	
Head Breadth	754	154.9	5.59	2993	154.7	5.67	0.22	0.98	
Head Circumference	754	579.4	15.69	2985	575.0	15.77	4.45	6.95	*
Head Length	754	201.1	6.92	2992	198.0	6.97	3.11	11.02	*
Knee Height, Sit	754	566.3	29.51	2984	559.2	25.26	7.15	6.11	*
Sitting Height	754	929.5	35.36	2993	921.8	34.45	7.68	5.36	*
Stature	754	1776.0	71.37	2989	1781.2	57.84	-5.11	-1.82	
Thumbtip Reach	754	829.7	48.35	2987	829.7	42	-0.01	-0.01	
Waist Circumference,O	754	1026.3	129.11	2988	906.1	94.57	120.18	23.99	*
Weight, kg	754	95.35	17.295	2991	83.31	11.950	12.04	18.06	*

*0.00313 Bonferroni's correction for multiple comparisons, at .05

The remainder of the results have to do with the amount of variability added by the various pieces of equipment officers carry for their own safety as well as for carrying out official duties. An example is seen in Figure 1. To identify the additional space occupied by the equipment, we calculated the differences (delta) between the measurements with gear and the nude measurements. For example, Bideltoid Breadth Delta = Bideltoid Breadth Gear – Bideltoid Breadth. Tables 4 and 5 show, for males and females respectively, both the mean value of the added equipment, as well as selected percentiles. The differences are largest in Hip Breadth, Sitting and Waist Breadth, Sitting. In both cases, the articles worn on the belt have a significant impact on the overall value. Notice also that the range of the deltas – from the 5th to the 95th percentiles of each dimension – is quite large.

Figure 1. Items worn on the torso and duty belt.

Table 4. Differences between Dimensions Measured with and without Gear: Males (weight in kg, all other values in mm).

		Bideltoid Breadth, Sitting Delta	Chest Breadth Delta	Chest Depth Delta	Hip Breadth, Sitting Delta	Stature Delta	Waist Breadth, Sitting Delta	Weight Delta
N		756	756	756	756	756	756	756
Mean		28.9	12.4	44.6	105.2	28.2	90.6	10.9
Std. Deviation		15.69	17.21	20.59	28.11	7.57	52.01	2.55
Percentiles	5	7	-16	16	53	16	12	6
	25	18	1	31	90	23	49	10
	50	28	13	42	108	28	88	11
	75	38	23	56	122	33	134	12
	95	58	40	84	146	41	172	15

Table 5. Differences between Dimensions Measured with and without Gear: Females (weight in kg, all other values in mm).

		Bideltoid Breadth, Sitting Delta	Chest Breadth Delta	Chest Depth Delta	Hip Breadth, Sitting Delta	Stature Delta	Waist Breadth, Sitting Delta	Weight Delta
N		218	218	218	218	217	217	218
Mean		31.7	24.5	40.6	70.2	29.5	120.4	9.2
Std. Deviation		14.79	17.27	21.46	32.08	7.92	51.30	2.09
Percentiles	5	7	-2	12	14	16	28	5
	25	24	13	27	53	25	86	8
	50	29	26	39	72	30	132	9
	75	38	36	55	90	35	159	11
	95	61	51	77	112	43	189	12

An interesting phenomenon occurs for Chest Breadth, where at the small end of the distribution the values are negative. In a handful of cases, the body armor compressed the chest enough that the value with gear was actually smaller than the nude value. The body armor was functioning as a corset for those individuals. We hypothesized that the addition of gear would also increase the variance of the measurements. Table 6 shows that the hypothesis was borne out in some cases, in particular for Bideltoid Breadth, Hip Breadth and Waist Breadth, but in the case of Chest Breadth, the addition of the gear seemed to reduce variability, probably as a result of the corset effect. For the remaining dimensions, the addition of gear did not appear to have much effect on the resulting variance.

Table 6. Standard Deviation Compared between Semi-Nude and Gear Dimensions: Males and Females Combined (weight in kg; all other values in mm).

		Semi-Nude	**Gear**
	N	Std. Deviation	Std. Deviation
Bideltoid Breadth, Sitting	974	40.83	43.95
Chest Breadth	974	40.52	34.71
Chest Depth	974	31.83	32.11
Hip Breadth, Sitting	974	35.26	37.53
Stature	973	87.00	87.18
Waist Breadth, Sitting	974	42.76	49.73
Weight, kg	974	18.67	19.44

4. Discussion and Conclusion

Previous efforts to model the police officer body envelope have been hampered by the lack of current anthropometric data on active police officers, and by a complete lack of data on the total amount of space occupied by encumbered officers. Since officers carry a wide variety of equipment on their body, these items can have significant impacts on the overall amount of occupied claim. The greatest increases in dimension were found at the waist and the hip. Both of these areas are affected by the items carried on the officer's duty belt. As a part of the questionnaire that accompanied the anthropometric survey, officers were asked to check off from a list of a dozen items that might be worn on the duty belt. Table 7 shows the list of items, ranked in order of frequency (males). The frequencies do not sum to 100% because officers carry many more than one item on their belt. A secondary question was whether items on the duty belt caused discomfort during a shift. Fully 74% of male officers and 85% of female officers reported that they did experience discomfort from belt-worn items. We did not collect data with respect to the specific location of each item on the belt. However, with the number of items carried, it is likely that some duty belt items would interfere with easy placement and fastening of the seat belt. Further, it is also likely that some combination of duty belt items would affect driving posture for at least some officers.

Table 7. Items Carried on the Duty Belt.

	Male		Female	
Handgun	677	92%	190	90%
Handcuffs	674	92%	195	92%
Ammunition pouch	645	88%	183	87%
Radio	639	87%	191	91%
Pepper Spray	588	80%	186	88%
Flashlight	581	79%	173	82%
Baton	447	61%	137	65%
Taser	419	57%	126	60%
Key Holder	375	51%	105	50%
Disposable Gloves	308	42%	93	44%
Knife	238	32%	66	31%
First Aid Kit	104	14%	19	9%

Also, of note is that males and females carry the items on their duty belt in roughly the same proportion. The items carried on the belt are generally not sized items – a taser, for example, is a certain size, no matter who carries it. For officers with smaller waists, and certainly for female officers with smaller waists, the *proportion* of the waist encumbered with equipment must therefore be comparatively larger than when the same equipment is carried on someone with a larger waist. To the extent that items carried on the belt are a cause of discomfort or restrict movement, the effect may be greater on persons with smaller waists and hips. From the perspective of vehicle design, however, the worst case is clearly the individual with wider hips, but who also carries multiple items on the sides of the duty belt.

Creators of digital human models for police vehicle design and protective equipment design may wish to use the updated anthropometric data from this survey when making models for the future. In particular, modelers may wish to take into account the considerable variability added by equipment worn at the waist and hip when configuring worst-case design envelopes. It is not enough to simply model the occupied space of, for example, the 95th percentile of hip breadth with gear. A smaller-hipped person with more gear, and a larger-hipped person with less gear might have the same overall width. But the models representing each should be different, as the various modeled actions (ingress, egress, behavior during a collision, for example) would be very different from each other. The work here is a very first step in allowing modelers to faithfully represent the equipped bodies of law enforcement personnel.

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.

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