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Hongwei Hsiao [a] , Daniel Long [a] & Karl Snyder [a]
[a] National Institute for Occupational Safety and Health, Division of Safety Research, Morgantown, WV 26505, USA
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HONGWEI HSIAO*, DANIEL LONG and KARL SNYDER

National Institute for Occupational Safety and Health, Division of Safety Research, Morgantown, WV 26505, USA

The increasing demands for anthropometric information for the design of machinery and personal protective equipment to prevent occupational injuries has necessitated an understanding of the anthropometric differences to be found among occupations. This study identified differences in various body measurements between occupational groups in the USA, as determined in the third National Health and Nutrition Examination Survey. Approximately 16,000 of its 32,900 subjects were associated with an occupational group. The analysis of the data showed that the body size, or body segment measurements, of some occupational groups differ significantly. For example, agricultural workers were shorter by an average of 2.5 cm in height, and had wider wrist breadths, than other workers. Female agricultural and manufacturing workers had larger waist circumferences than those in the 'other occupations' and 'all occupations' categories. Protective service workers (i.e. firefighters, police and guards) were taller and heavier (7 kg heavier for males and over 10 kg heavier for females) than those in all occupations combined. These differences and other deviations as well as some age-and-ethnicity-adjusted results were tabulated for users' reference. Researchers and designers who use anthropometric databases to evaluate human-machine interfaces and personal protective equipment (PPE) must use caution in selecting databases that are adequate for their occupational applications.

Keywords: Anthropometry; Occupation; Human size; Agriculture; Construction; Personal protective equipment

1. Introduction

In occupational injury prevention applications, anthropometric measurements are used to evaluate the interaction of workers with tasks, tools, machines, vehicles and personal protective equipment. Designs that are incompatible with anthropometric measurements of a workforce could result in undesired incidents. The mismatch of a heavy-vehicle operator's station to a driver could produce blind spots that limit safe operation. The misfit of a respirator could result in serious health effects in firefighting, hazardous waste clean-up, and other workplace conditions (Hsiao and Halperin 1998). Inadequate crew station geometry was found to be a contributor to some crew members' injuries during ejection from aircraft (Rice and Ninow 1973). Inadequate height and step clearance for heavy-vehicle access systems have been identified as common causes of falls among vehicle operators (Albin and Adams 1990, Couch and Fraser 1981). The fit of both children and older workers to machinery designed for the general working population is also a concern to the safety community (Bottoms and Butterworth 1990). As demonstrated by these

*Author for correspondence at 1095 Willowdale Road, Morgantown, West Virginia 265065, USA; e-mail: hhsiao@cdc.gov

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examples, a design process that makes use of anthropometric data and methods must consider the potential for large variations in body dimensions from population to population.

While literature has shown that gender, age, race, and geographical region are associated with differences in body dimensions (SAE International 1998), little information is available regarding anthropometric differences among occupational groups. Researchers, in a laboratory simulation study, have observed differences in muscle strength capacity between subjects drawn from construction and manufacturing workforces (Cutlip *et al*., 2000). Bradtmiller *et al*. (2000), citing a final report on an anthropometric survey of luxury car buyers, indicated that there were significant differences (such as weight, waist circumference, and buttock depth) between different occupational and income groups. Diverse workforces in some occupations also make the anthropometric differences between occupations more pronounced, while new roles for women in the workforce make it likely that more occupations will show a broader range of body dimensions. Since different occupational groups perform different jobs, use of inappropriate or inadequate group anthropometric data for designing workplaces, systems, and personal protective devices is a serious safety concern.

This paper reports the anthropometric differences among occupations with a focus on body dimensions. The information is important for researchers who use human-form databases in evaluating human-machine interfaces and personal protective equipment (PPE), for designers who formulate anthropometric guides for the development and selection of correct sizes of PPE, and for anthropometry research managers in determining their sampling strategies.

2. Method

This study analysed the third National Health and Nutrition Examination Survey (NHANES III 1988–94) data to identify differences in various physical body measurements between occupation groups (US Department of Health and Human Services [DHHS] 1996a). NHANES III is a nationwide probability sample of 33,994 persons aged 2 months and over in the 50 states of the USA and the District of Columbia. The NHANES III survey was the first NHANES without an upper age limit; however, for confidentiality reasons those aged 90 years or greater were assigned to a single category of 90+ years. The NHANES III survey utilized complex, multi-stage, stratified, clustered samples of civilian, noninstitutionalized populations. In the first stage of the design, 81 primary sampling units (mostly individual counties) consisting of 89 locations were selected. The 89 locations were randomly divided into two groups (44 and 45 locations), one for each phase in which the study was conducted. The first study period was from 1988 to 1991 while the second period was from 1991 to 1994. The survey was conducted by the National Center for Health Statistics and was designed to obtain nationally representative information on the health and nutritional status of the population of the USA through interviews and direct physical examinations. The primary goal of NHANES III was to estimate the number and percentage of persons in the US population and designated subgroups with selected diseases and risk factors. Various body measurements of the study subjects were collected.

The study utilized these body measurements to investigate anthropometric differences among occupational subgroups. The body measurements analysed are listed in table 1. The NHANES III data used for this study were contained on the

Table 1. Descriptions and definitions of body measurements (US DHHS 1996b).

Description	Definition
Stature (cm)	Distance from the bottom of the feet (heels together and toes angled at 60°) to the top of the head (positioned in Frankfort horizontal plane) with the hair compresses, as measured by a fixed stadiometer with a vertical backboard with the subject standing upright, feet flat and heels, buttocks, scapula, and back of head contacting vertical board
Weight (kg)	Body weight of the subject wearing only underwear and paper examination gown as measured by an electronic load cell scale
Body mass index	Weight/(Height/100)^2 (weight in kg and height in cm)
Sitting height (cm)	Measurement from the buttocks to the top of the head (placed in Frankfort plane) with the hair compressed, as measured by a fixed stadiometer with the subject sitting upright on a box
Upper arm length (cm)	Distance from the upper-most edge of the posterior border of the acromion process of the right scapula to the tip of the olecranon process of the elbow as measured by a metal tape placed down the middline of the posterior of the arm
Bi-acromial breadth (cm)	Distance as measured with a sliding caliper between the lateral borders of the acromial processes
Bi-iliac breadth (cm)	Distance as measured with a sliding caliper between the uppermost lateral borders of each ilium on a midaxillary line
Elbow breadth (cm)	Distnce as measured with a sliding caliper between the epicondyles of the humerus
Wrist breadth (cm)	Distance as measured with a sliding caliper between the most prominent aspects of the styloid processes of the ulna and radius
Arm circumference (cm)	Circumference of the arm as measured by a metal tape placed at the midpoint of the upper arm length
Waist circumference (cm)	Circumference of the waist as measured by a metal tape placed in the horizontal plane at the upper-most lateral border of the right ilium
Buttocks circumference (cm)	Circumference as measured by a metal tape placed in the horizontal plane at the maximum protuberance of the buttocks
Thigh circumference (cm)	Circumference of the thigh as measured by a metal tape placed in the horizontal plane at the midpoint of the upper leg length
Upper leg length (cm)	Measurement from the inguinal crease of the anterior superior iliac spine to the proximal patella, as measured by a metal tape extended along the anterior midline of the thigh

NHANES III, 1988–1994 CD-ROM Series 11 No. 1A. This CD-ROM series contained five directories (Adult, Youth, Exam, Lab and Foods) of which two (Adult and Exam) contained the variables applicable to this study. The coding files provided in the Adult and Exam directories were used to create corresponding data sets. These data sets were then merged using the survey participant identification number (SEQN) variable. This merging resulted in one data set with cases aged 17 years and older containing both the occupational and body measurements information.

The occupational grouping of each case was determined from question HAS17r of the NHANES III Adult directory. The classification of occupation for this question was based on categories defined by the US Bureau of Census in 1980 (US Bureau of Census 1981). This question asked, 'Thinking of all the paid jobs or

businesses you have ever had, what kind of work were you doing the longest?' The cases were grouped further to obtain larger agriculture, construction, protective service (i.e. firefighters, police, and guards), manufacturing, and mechanics and repairers occupational groupings. The occupational subgroups which were included in each occupational category are listed in table 2. Due to anthropometric differences between genders, male and female data were analysed separately. In addition, among females, subjects who were pregnant were excluded from analysis due to anthropometric variations during pregnancy.

NHANES III is based on a complex, multi-stage probability sample design. Sample weights are used to estimate measures such as prevalence, means and medians. In addition, the strata and primary sampling unit (PSU) pairings from the sample design are taken into account for estimating variances and in tests for statistical significance. To conduct this weighted analysis, the SUDAAN software package (Shah *et al.*, 1997) was utilized, which is appropriate for variance estimation of complex samples.

The means of the various physical measurements by occupational group were determined and 95% confidence intervals about the mean were calculated. When minimum sample size requirements are met, confidence intervals about the mean can be computed using a normal approximation as $(p \pm Z \times s)$, where p is the statistic of interest (in this case the mean), Z is the value of the normal deviate with a selected level of significance (in this study $Z = 1.96$ was used for the 95% confidence interval), and s is an estimate of the sampling error of p under the complex sample design (US DHHS 1996b). The means and 95% confidence intervals for the five occupational subgroups plus the 'other occupations' group were compared to each other as well as to the total number of people from all occupations. Groups were considered significantly different if their 95% confidence intervals did not overlap (table 3). This is equivalent to a two-tail t-test with a p-value of 0.025 as the significance level.

Table 2. The occupational subgroups in each occupational category.

Agriculture	Protective services
Farm operators, managers and supervisors	Firefighting and fire prevention occupations
Farm and nursery workers	Police and detectives
Related agricultural, forestry, and fishing occupations	Guards
Construction	**Mechanics and repairers**
Construction trades	Vehicle & mobile equipment mechanics & repairers
Construction labourers	Other mechanics and repairers
Manufacturing	**Other occupations**
Extractive and precision production occupations	Executive, administrative, managerial
Textile, apparel and furnishings machine operators	Professional specialty
Machine operators, assorted materials	Service and sales
Fabricators, assemblers, inspectors and samplers	Technicians, administrative support, etc.

Table 3. Anthropometric differences among occupational groups (part 1 of 5).

		Males				Females			
Variable[†]	Occupational group[‡]	N[§]	Mean	95% Confidence interval	SI**	N[§]	Mean	95% Confidence interval	SI**
Stature	Agriculture	905	173.3	172.3 – 174.4	A	335	159.2	157.8 – 160.7	A
	Construction	813	175.2	174.3 – 176.1	ABC	18*	163.2	160.1 – 166.4	ABC
	Manufacturing	1338	174.1	173.4 – 174.9	A	1321	159.7	159.1 – 160.4	A
	Protec Service	146	177.7	175.8 – 179.6	BC	43	166.0	163.0 – 169.0	B
	Mech/Repair	518	175.2	174.1 – 176.3	ABC	25*	164.0	161.3 – 166.7	BC
	Other Occup	4241	176.4	176.1 – 176.6	B	6763	162.4	162.1 – 162.6	C
	All Occup	7961	175.7	175.4 – 175.9	C	8505	162.0	161.7 – 162.3	C
Weight	Agriculture	906	80.5	78.4 – 82.5	A	331	68.7	65.9 – 71.6	A
	Construction	813	80.7	79.0 – 82.5	A	18*	62.8	56.3 – 69.3	A
	Manufacturing	1338	80.5	79.3 – 81.7	A	1318	70.4	68.8 – 72.0	A
	Protec Service	146	88.8	84.3 – 93.2	B	43	79.2	73.0 – 85.3	B
	Mech/Repair	518	83.2	80.6 – 85.9	AB	24*	74.4	64.7 – 84.1	AB
	Other Occup	4238	82.0	81.1 – 82.9	A	6756	68.6	67.9 – 69.4	A
	All Occup	7959	81.8	81.1 – 82.5	A	8490	68.9	68.2 – 69.9	A
BMI	Agriculture	876	26.8	26.0 – 27.5	AB	322	27.2	26.1 – 28.2	AB
	Construction	794	26.3	25.8 – 26.7	AB	18*	23.8	20.5 – 27.1	AB
	Manufacturing	1308	26.6	26.2 – 26.9	AB	1284	27.6	26.9 – 28.3	A
	Protec Service	143	28.1	26.6 – 29.6	B	43	28.7	26.5 – 31.0	AC
	Mech/Repair	504	27.1	26.5 – 27.7	AB	24*	27.6	23.9 – 31.3	AB
	Other Occup	4156	26.3	26.0 – 26.6	A	6576	26.0	25.8 – 26.3	B
	All Occup	7781	26.5	26.2 – 26.7	AB	8267	26.3	26.0 – 26.6	BC

[†]Stature: Standing height (cm), Weight: Weight (kg), BMI: Body mass index.
[‡]Agriculture: Agriculture occupations, Construction: Construction occupations, Manufacturing: Manufacturing occupations, Protec Service: Protective service occupations, Mech/Repair: Mechanics and repairers, Other Occup: Other occupations, All Occup: All occupations.
[§]N: sample size (raw data). NCHS recommends a minimum sample size of 30 for estimation of any mean.
*Indicates that a sample size of < 30 appears in the table.
**SI: Significance Indicator. Means with the same letter are not significantly different. Groups were significantly different if their 95% confidence intervals did not overlap.

Table 3. Anthropometric differences among occupational groups (part 2 of 5).

		Males				Females			
Variable†	Occupational group‡	N§	Mean	95% Confidence interval	SI**	N§	Mean	95% Confidence interval	SI**
Sitting Ht.	Agriculture	843	90.8	90.2–91.3	B	307	83.7	82.7–84.7	C
	Construction	777	91.7	91.3–92.2	ABC	18*	86.2	84.5–87.8	ABC
	Manufacturing	1285	91.1	90.8–91.5	B	1259	84.3	84.0–84.6	C
	Protec Service	141	93.1	92.1–94.1	AC	41	87.7	86.3–89.1	A
	Mech/Repair	497	92.0	91.5–92.5	AC	25*	86.1	83.5–88.7	ABC
	Other Occup	4077	92.3	92.0–92.5	AC	6452	85.8	85.6–85.9	B
	All Occup	7620	92.0	91.8–92.1	AC	8102	85.5	85.4–85.7	B
U Arm L	Agriculture	829	37.8	37.5–38.1	AB	293	34.5	34.0–34.9	BC
	Construction	771	38.0	37.7–38.2	A	18*	35.0	34.3–35.8	AB
	Manufacturing	1254	37.5	37.2–37.7	B	1235	34.5	34.4–34.7	B
	Protec Service	138	38.0	37.4–38.7	AB	40	35.7	34.8–36.7	AC
	Mech/Repair	496	38.0	37.7–38.3	AB	25*	35.9	35.1–36.7	A
	Other Occup	3993	37.8	37.7–37.9	AB	6310	34.6	34.5–34.6	B
	All Occup	7481	37.8	37.7–37.9	A	7921	34.6	34.5–34.6	B
U leg L	Agriculture	822	41.9	41.3–42.5	AB	289	37.7	37.1–38.4	A
	Construction	761	42.4	41.9–42.9	AB	17*	39.3	37.1–41.5	ABC
	Manufacturing	1241	41.8	41.4–42.2	A	1231	37.8	37.3–38.2	A
	Protec Service	138	42.9	42.2–43.5	B	40	40.8	39.6–42.0	C
	Mech/Repair	492	42.2	41.8–42.7	AB	25*	37.4	36.3–38.4	A
	Other Occup	3968	42.6	42.3–42.9	B	6267	38.9	38.6–39.1	B
	All Occup	7422	42.4	42.1–42.7	AB	7869	38.7	38.5–39.0	B

†Sitting Ht.: Sitting height (cm), U Arm L: Upper arm length (cm), U leg L: Upper leg length (cm).
‡Agriculture: Agriculture occupations, Construction: Construction occupations, Manufacturing: Manufacturing occupations, Protec Service: Protective service occupations, Mech/Repair: Mechanics and repairers, Other Occup: Other occupations, All Occup: All occupations.
§*N*: sample size (raw data). NCHS recommends a minimum sample size of 30 for estimation of any mean.
*Indicates that a sample size of <30 appears in the table.
**SI: Significance Indicator. Means with the same letter are not significantly different. Groups were significantly different if their 95% confidence intervals did not overlap.

Table 3. Anthropometric differences among occupational groups (part 3 of 5).

		Males				Females			
Variable[†]	Occupational group[‡]	N[§]	Mean	95% Confidence interval	SI**	N[§]	Mean	95% Confidence interval	SI**
Biacro. B	Agriculture	832	41.0	40.7–41.3	AC	294	36.2	35.9–36.6	A
	Construction	770	41.3	41.0–41.5	AC	18*	36.7	35.8–37.6	A
	Manufacturing	1259	40.9	40.7–41.2	BC	1239	36.6	36.4–36.9	A
	Protec Service	138	41.8	41.3–42.3	A	40	37.3	36.3–38.3	A
	Mech/Repair	496	41.4	40.9–41.8	AC	24*	37.3	36.3–38.3	A
	Other Occup	3994	41.1	40.9–41.2	BC	6321	36.7	36.5–36.9	A
	All Occup	7489	41.1	41.0–41.3	BC	7936	36.7	36.5–36.9	A
Biiliac B	Agriculture	824	29.8	29.4–30.2	A	291	29.5	28.8–30.1	ACD
	Construction	764	29.3	29.0–29.6	A	18*	28.4	27.2–29.6	BC
	Manufacturing	1249	29.4	29.2–29.6	A	1227	29.6	29.3–29.8	AC
	Protec Service	138	29.9	29.4–30.5	A	40	30.5	29.6–31.5	A
	Mech/Repair	494	29.8	29.4–30.2	A	25*	30.1	28.0–32.1	ACD
	Other Occup	3975	29.6	29.4–29.8	A	6288	28.9	28.7–29.1	BD
	All Occup	7444	29.6	29.4–29.7	A	7889	29.0	28.9–29.2	BD
Elbow B	Agriculture	835	7.38	7.32–7.44	A	301	6.63	6.53–6.73	C
	Construction	773	7.43	7.37–7.49	A	18*	6.55	6.33–6.77	AC
	Manufacturing	1259	7.37	7.31–7.43	A	1242	6.54	6.50–6.58	BC
	Protec Service	138	7.37	7.25–7.49	A	40	6.50	6.32–6.68	AC
	Mech/Repair	496	7.43	7.35–7.51	A	25*	6.63	6.22–7.04	AC
	Other Occup	4012	7.35	7.33–7.37	A	6341	6.46	6.42–6.50	AB
	All Occup	7513	7.37	7.35–7.39	A	7967	6.47	6.45–6.49	A

[†]Biacro. B: Biacromial breadth (cm), Biiliac B: Biiliac breadth (cm), Elbow B: Elbow breadth (cm).
[‡]Agriculture: Agriculture occupations, Construction: Construction occupations, Manufacturing: Manufacturing occupations, Protec Service: Protective service occupations, Mech/Repair: Mechanics and repairers, Other Occup: Other occupations, All Occup: All occupations.
[§]N: sample size (raw data). NCHS recommends a minimum sample size of 30 for estimation of any mean.
*Indicates that a sample size of <30 appears in the table.
**SI: Significance Indicator. Means with the same letter are not significantly different. Groups were significantly different if their 95% confidence intervals did not overlap.

Table 3. Anthropometric differences among occupational groups (part 4 of 5).

		Males				Females			
Variable[†]	Occupational group[‡]	N[§]	Mean	95% Confidence interval	SI**	N[§]	Mean	95% Confidence interval	SI**
Waist C	Agriculture	818	95.0	93.4 – 96.5	A	291	91.9	89.0 – 94.9	B
	Construction	762	93.3	92.0 – 94.7	A	18*	82.2	75.1 – 89.3	AB
	Manufacturing	1246	95.4	94.3 – 96.6	A	1228	92.1	90.5 – 93.7	B
	Protec Service	138	97.5	94.2 – 100.8	A	40	93.6	86.5 – 100.7	AB
	Mech/Repair	494	96.4	94.6 – 98.2	A	25*	94.4	87.4 – 101.4	AB
	Other Occup	3966	94.4	93.7 – 95.1	A	6269	87.4	86.7 – 88.1	A
	All Occup	7424	94.7	94.2 – 95.2	A	7871	88.1	87.4 – 88.8	A
Butt. C	Agriculture	818	98.6	97.5 – 99.7	A	291	101.9	99.8 – 103.9	AB
	Construction	762	98.1	97.1 – 99.2	A	18*	98.1	92.1 – 104.1	AB
	Manufacturing	1245	98.7	98.0 – 99.4	A	1228	103.4	102.4 – 104.7	BC
	Protec Service	138	102.0	99.7 – 104.2	B	40	107.3	103.1 – 111.5	B
	Mech/Repair	493	100.3	99.0 – 101.6	AB	25*	103.2	96.4 – 110.0	AB
	Other Occup	3969	99.7	99.2 – 100.1	AB	6276	101.7	101.2 – 102.2	A
	All Occup	7425	99.4	99.1 – 99.7	A	7878	101.9	101.4 – 102.5	AC
Thigh C	Agriculture	815	50.9	50.3 – 51.6	A	288	50.6	49.4 – 51.8	A
	Construction	759	51.6	51.0 – 52.2	AB	17*	49.6	46.0 – 53.2	AB
	Manufacturing	1232	51.3	50.9 – 51.7	A	1226	51.0	50.4 – 51.6	A
	Protec Service	138	53.4	52.1 – 54.6	B	40	55.5	53.0 – 58.0	B
	Mech/Repair	492	52.1	51.2 – 53.0	AB	25*	50.9	46.8 – 55.0	AB
	Other Occup	3951	51.8	51.5 – 52.1	A	6240	51.0	50.8 – 51.3	A
	All Occup	7387	51.7	51.5 – 51.9	A	7836	51.0	50.8 – 51.3	A

[†]Waist C: Waist circumference (cm), Butt. C: Buttocks circumference (cm), Thigh C: Thigh circumference.
[‡]Agriculture: Agriculture occupations, Construction: Construction occupations, Manufacturing: Manufacturing occupations, Protec Service: Protective service occupations, Mech/Repair: Mechanics and repairers, Other Occup: Other occupations, All Occup: All occupations.
[§]*N*: sample size (raw data). NCHS recommends a minimum sample size of 30 for estimation of any mean.
*Indicates that a sample size of <30 appears in the table.
**SI: Significance Indicator. Means with the same letter are not significantly different. Groups were significantly different if their 95% confidence intervals did not overlap.

Table 3. Anthropometric differences among occupational groups (part 5 of 5).

		Males				Females			
Variable[†]	Occupational group[‡]	$N^{\S}$	Mean	95% Confidence interval	SI**	$N^{\S}$	Mean	95% Confidence interval	SI**
Wrist B	Agriculture	836	6.03	5.97–6.09	A	301	5.30	5.24–5.36	B
	Construction	774	5.98	5.94–6.02	AC	18*	5.25	5.07–5.43	AB
	Manufacturing	1258	5.93	5.89–5.97	AB	1238	5.25	5.23–5.27	B
	Protec Service	138	5.88	5.82–5.94	B	40	5.24	5.12–5.36	AB
	Mech/Repair	495	5.95	5.89–6.01	AB	25*	5.27	5.13–5.41	AB
	Other Occup	4015	5.89	5.87–5.91	B	6340	5.16	5.14–5.18	A
	All Occup	7516	5.92	5.90–5.94	BC	7962	5.17	5.15–5.19	A
Arm C	Agriculture	855	32.7	32.3–33.1	A	302	31.3	30.4–32.1	AB
	Construction	786	33.2	32.8–33.5	A	18*	28.6	26.4–30.8	BC
	Manufacturing	1281	32.8	32.4–33.1	A	1267	31.3	30.8–31.9	AC
	Protec Service	141	34.1	33.1–35.1	A	40	32.9	31.2–34.7	A
	Mech/Repair	506	33.4	32.8–33.9	A	25*	31.6	29.0–34.2	AB
	Other Occup	4064	32.8	32.6–33.1	A	6455	30.4	30.2–30.6	B
	All Occup	7633	32.9	32.7–33.1	A	8107	30.5	30.3–30.8	BC

[†]Wrist B: Wrist breadth (cm), Arm C: Arm circumference (cm).
[‡]Agriculture: Agriculture occupations, Construction: Construction occupations, Manufacturing: Manufacturing occupations, Protec Service: Protective service occupations, Mech/Repair: Mechanics and repairers, Other Occup: Other occupations, All Occup: All occupations.
[§]*N*: sample size (raw data). NCHS recommends a minimum sample size of 30 for estimation of any mean.
*Indicates that a sample size of <30 appears in the table.
**SI: Significance Indicator. Means with the same letter are not significantly different. Groups were significantly different if their 95% confidence intervals did not overlap.

3. Results

A comparison of the anthropometric variables analysed for this study is shown in table 3 for males and females. The mean stature of male agriculture workers (173.3 cm) was found to be shortest among the comparison groups and is nearly 2.5 cm shorter than the mean of all occupational groups combined. Among females, agriculture workers are also shorter in stature with a mean height (159.2 cm) that is 2.8 cm less than all workers combined. The 95% confidence intervals for both male and female agricultural workers are statistically significantly shorter than those for all occupations combined. This relationship also follows for sitting height, with the mean sitting height for male agricultural workers (90.8 cm) and female agriculture workers (83.7 cm) being significantly shorter than male and female sitting heights for all occupations combined. The average wrist breadth of agricultural workers was found to be wider than that of other workers. Female agricultural workers also showed significantly larger values for elbow breadth and waist circumference and significantly shorter values for upper leg length.

The construction and the mechanics and repairers occupational groups showed very few significant differences when compared to other occupational groups. In fact, construction workers were not significantly different in any variables when compared to all occupations combined. Only female mechanics and repairers showed significantly longer upper arm lengths and significantly shorter upper leg lengths.

When compared to all occupations, those in protective service occupations had the tallest mean standing heights among both males and females (177.7 cm and 166.0 cm, respectively), which are 2 cm greater in males and 4 cm greater in females than the all occupations combined category for each respective group. The 95% confidence interval for height among female protective service occupation workers were significantly different than that for all occupations combined. The height of male protective service occupation workers bordered on being significantly different than male height for all occupations combined.

The mean weights of protective service officers were also greater than the other occupational groups examined: 7 kg heavier for males and over 10 kg heavier for females. Using the 95% confidence intervals, the mean weights for both male and female protective service officers were significantly higher than the male and female weights for all occupations combined. In addition, buttock and thigh circumference were significantly greater among both male and female protective service officers. Further, female protective service officers had significantly greater upper arm length, arm circumference, and bi-iliac breadth than several occupations, as well as all occupations combined. The biacromial breadth of the male protective service group was significantly greater than that of all occupations combined.

Workers in manufacturing occupations showed a trend similar to those in agricultural occupations, with both males and females being significantly shorter in both standing and sitting heights when compared to all occupations combined. Females in manufacturing were also significantly different from all occupations in many variables in which males showed no significant differences. Female manufacturing workers showed significantly smaller upper arm and upper leg lengths and significantly larger body mass index, bi-iliac breadth, elbow breadth, wrist breadth, and waist circumference when compared to all occupational groups combined.

4. Discussion

Demographic effects (geographical region, age and race) on anthropometry have been well reported in the literature. The geographical region issue should not be a concern in this analysis since the NHANES III has sampled 89 locations over the USA (§2).

Differences in age and race distributions among occupations may be confounding contributing factors to the differences seen in anthropometric variables between occupations. For example, the manufacturing and agricultural groups had higher percentages of workers older than 64 years of age, as compared to other groups (table 4). In addition, the agricultural group seemed to be more diversified in ethnicity distribution than other groups (table 5). The fact that these factors may have an influence on anthropometric variables within occupational groups is not disputed; however, occupational factors (e.g. self-selection, job effect) also very likely affect the anthropometric variables among occupational groups. Coal miners, for example, were reported to be shorter in stature than other workers in UK in the nineteenth century, a demographic variable that was attributable to self-selection and job factors, even though they enjoyed an above average food intake by nineteenth-century working-class standards (Kirby 1995). The self-selection referred to occupational selection of shorter genotype parents, maintained by high levels of occupational succession. The job factors referred to a high degree of muscular

Table 4. Percentage of each age group within each occupational group.

	Age (years)					
Occupation	17 – 24	25 – 34	35 – 44	45 – 54	55 – 64	> 64
Agriculture	18.2	17.0	14.0	11.4	11.5	27.9
Construction	14.9	28.9	23.5	12.7	9.0	10.9
Manufacturing	8.9	20.7	20.7	14.5	14.1	21.2
Protective Service	14.0	29.7	33.0	8.7	6.6	8.1
Mechanics and Repairers	13.9	20.2	24.2	14.1	13.4	14.2
Other	15.9	22.9	22.1	13.4	11.1	14.5
All occupations	14.9	22.7	21.8	13.4	11.5	15.7

Table 5. Percentage of each race-ethnicity group within each occupational group.*

	Ethnicity		
Occupation	Non-Hispanic White	Non-Hispanic Black	Mexican-American
Agriculture	66.5	7.6	16.1
Construction	77.2	9.6	6.8
Manufacturing	72.9	11.5	7.1
Protective service	79.9	12.8	4.0
Mechanics and repairers	80.9	6.5	4.8
Other	77.8	11.1	3.8
All occupations	76.8	10.8	5.0

*The percentages are based on weighted estimates, not the raw numbers. The percentage within each occupation doesn't add to 100% because the 'other ethnicity group' is not presented in this table.

development for job needs at the expense of the other organs, and long periods of exclusion from ultra-violet radiation caused mining children to experience suppressed skeletal development and to be shorter than their working-class contemporaries.

Table 6 shows anthropometric differences among occupations for two selected measurements (male stature and female waist circumference) by age and ethnicity. The results are similar to those in table 3 in which age and ethnicity were not adjusted. For example, male agricultural workers were shorter with a mean height of 173.3 cm, which is 3.1 cm less than all male workers in the 'other occupations' category (see table 3, part 1 of 5). An analysis of the occupation effect within each of six age groups showed a similar trend (see table 6, part 1 of 4). This occupation effect was particularly significant within the 25–34 years, 35–44 years, 45–54 years and 55–64 years age groups (4.0 cm, 4.8 cm, 4.2 cm, and 3.9 cm differences, respectively, which were statistically significant). Another analysis on the occupation effect by ethnic group also showed that the mean stature of male agriculture workers was 1.8 cm, 2.0 cm, and 3.0 cm less than that of workers within the 'other occupations' category for each of the three listed ethnic groups, although the difference was not statistically significant for the non-Hispanic black group (table 6, part 2 of 4). Similarly, female agricultural workers had larger waist circumference (4.5 cm mean difference) than the 'other occupations' workers when age and ethnicity adjustments were not employed (table 3, part 4 of 5). With ethnicity adjustment (table 6, part 3 of 4), the mean difference was in the range of 3.5 cm (non-Hispanic White, not statistically significant), to 5.5 cm (non-Hispanic Black, statistically significant), to 7 cm (Mexican-American, statistically significant). On the other hand, the occupation effect on female waist circumference is heavily confounded with age effect as indicated in table 6, part 4 of 4. The important message from this study is that the body segment measurements of some occupational groups differed significantly and occupational factors seemed to play an important role on the differences, in addition to gender, age and ethnicity effects.

5. Summary

These results indicate that the body sizes and shapes of some occupational groups are quite different. The differences are tabulated in tables 3 and 6 for users' reference. The application of anthropometric data from one occupational group to another, or from the general population to a specific occupational group, in the design of workplaces, systems, and personal protective devices, can be inappropriate. When determining their sampling strategies, anthropometry research managers need to consider potential differences in body sizes and shapes between occupational groups in order to obtain the most useful data for engineering applications. Researchers who use human-form databases to evaluate human-machine interfaces and personal protective equipment (PPE) also have to be cautious in selecting adequate databases for their applications. Designers who formulate anthropometric guides for the development and selection of PPE sizes need to incorporate the correct data for the target occupations in the guideline development process. Finally, a computerized anthropometric database with occupational and demographic raw data (especially with three-dimensional human forms) would be a helpful tool for future applied anthropometric research in addressing occupational safety and ergonomics concerns.

Table 6. 'Adjusted' anthropometric differences among occupational groups. Part 1 of 4: male stature (cm) by age.

	Age								
	17–24			25–34			35–44		
Occupational group	Mean [N]§	95% CI	SI**	Mean [N]§	95% CI	SI**	Mean [N]§	95% CI	SI**
Agriculture	176.9 [134]	174.8–179.0	A	172.9 [124]	170.4–175.5	A	172.7 [86]	170.3–175.1	A
Construction	175.5 [114]	173.7–177.2	A	176.1 [174]	174.4–177.8	AB	177.1 [156]	174.4–179.7	AB
Manufacturing	174.9 [130]	172.4–177.3	A	174.1 [265]	172.9–175.3	A	175.8 [236]	173.9–177.7	AB
Protective service	–*	–	–	176.5 [34]	171.7–181.4	AB	179.0 [45]	175.8–182.3	B
Mechanics and repairers	176.9 [59]	174.5–179.2	A	177.1 [87]	175.1–179.1	AB	176.2 [87]	172.6–179.7	AB
Other occupations	177.1 [703]	176.3–178.0	A	176.9 [821]	176.1–177.6	B	177.5 [731]	176.8–178.1	B
All occupations	176.7 [1151]	176.1–177.4	A	176.2 [1505]	175.5–176.8	B	177.0 [1341]	176.4–177.5	B
	Age								
	45–54			55–64			>64		
Occupational group	Mean [N]§	95% CI	SI**	Mean [N]§	95% CI	SI**	Mean [N]§	95% CI	SI**
Agriculture	172.4 [68]	170.4–174.4	A	172.1 [101]	170.4–173.8	A	171.9 [392]	170.9–173.0	AB
Construction	175.8 [86]	173.9–177.8	AB	171.5 [88]	169.5–173.5	A	170.4 [195]	169.1–171.7	A
Manufacturing	173.5 [174]	171.5–175.5	AB	174.5 [190]	172.9–176.0	AB	171.8 [343]	170.9–172.7	AB
Protective service	–*	–	–	–*	–	–	–*	–	–
Mechanics and repairers	175.2 [70]	172.7–177.8	AB	174.2 [85]	171.7–176.6	AB	170.5 [130]	168.6–172.3	AB
Other occupations	176.6 [478]	175.7–177.4	B	176.0 [510]	175.2–176.7	B	172.8 [998]	172.2–173.4	B
All occupations	175.7 [890]	175.0–176.3	B	175.0 [990]	174.4–175.6	B	172.2 [2084]	171.9–172.6	B

*NCHS recommends a minimum sample size of 30 for reporting; any statistics based on sample size <30 was not reported in this table.
**SI: Significance Indicator; means with the same letter are not significantly different.
§[N]: sample size (unwighted raw data).

Table 6. 'Adjusted' anthropometric differences among occupational groups. Part 2 of 4: male stature (cm) by etnic group.

	Ethnicity								
	Non-Hispanic White			Non-Hispanic Black			Mexican-American		
Occupational group	Mean [N][§]	95% CI	SI**	Mean [N][§]	95% CI	SI**	Mean [N][§]	95% CI	SI**
Agriculture	175.2 [332]	173.9–176.5	A	174.5 [125]	172.7–176.4	AB	167.8 [424]	166.9–168.6	A
Condtruction	176.2 [298]	175.1–177.2	A	174.7 [194]	173.6–175.8	A	169.9 [292]	169.5–170.2	B
Manufacturing	174.9 [489]	174.1–175.7	A	176.2 [370]	175.4–177.0	AB	169.3 [438]	168.6–170.0	A
Protective service	178.9 [60]	177.1–180.7	B	175.5 [51]	173.4–177.6	AB	173.5 [34]	170.3–176.7	C
Mechanics and repairers	176.3 [262]	175.4–177.2	AB	175.6 [90]	173.4–177.8	AB	170.3 [143]	169.1–171.5	BC
Other occupations	177.0 [1844]	176.7–177.4	B	176.5 [1267]	176.1–177.0	B	170.8 [966]	170.2–171.4	BC
All occupations	176.5 [3285]	176.2–176.8	AB	176.2 [2097]	175.9–176.4	B	169.9 [2297]	169.5–170.2	B

Table 6. 'Adjusted' anthropometric differences among occupational groups. Part 3 of 4: female waist circumference (cm) by age group.

	Age								
	17–24			25–34			35–44		
Occupational group	Mean [N][§]	95% CI	SI**	Mean [N][§]	95% CI	SI**	Mean [N][§]	95% CI	SI**
Agriculture	–*	–	–	–*	–	–	92.4 [43]	85.7–99.2	A
Construction	–*	–	–	–*	–	–	–*	–	–
Manufacturing	82.6 [110]	78.8–86.4	A	87.1 [244]	83.4–90.8	A	89.7 [259]	86.9–92.6	A
Protective service	–*	–	–	–*	–	–	–*	–	–
Mechanics and repairers	–*	–	–	–*	–	–	–*	–	–
Other occupations	79.8 [1073]	78.7–80.9	A	83.4 [1359]	82.2–84.6	A	87.9 [1232]	86.5–89.2	A
All occupations	79.9 [1221]	78.8–81.1	A	84.1 [1657]	82.9–85.2	A	88.2 [1552]	86.8–89.6	A

	Age								
	45–54			55–64			>64		
Occupational group	Mean [N][§]	95% CI	SI**	Mean [N][§]	95% CI	SI**	Mean [N][§]	95% CI	SI**
Agriculture	93.9 [37]	88.3–99.5	A	102.9 [45]	99.2–106.7	A	92.8 [116]	89.7–96.0	A
Construction	–*	–	–	–*	–	–	–*	–	–
Manufacturing	93.3 [144]	90.6–96.0	A	98.8 [181]	95.9–101.7	AC	95.0 [305]	92.2–97.9	A
Protective service	–*	–	–	–*	–	–	–*	–	–
Mechanics and repairers	–*	–	–	–*	–	–	–*	–	–
Other occupations	91.8 [742]	90.0–93.5	A	94.0 [731]	92.5–95.5	B	92.8 [1265]	91.9–93.7	A
All occupations	92.0 [930]	90.4–93.6	A	95.2 [966]	93.9–96.4	BC	93.2 [1695]	92.4–94.0	A

Table 6. 'Adjusted' anthropometric differences among occupational groups. Part 4 of 4: female waist circumference (cm) by etnic group.

	Ethnicity								
	Non-Hispanic White			Non-Hispanic Black			Mexican-American		
Occupational group	Mean [N]§	95% CI	SI**	Mean [N]§	95% CI	SI**	Mean [N]§	95% CI	SI**
Agriculture	90.4 [72]	85.4–95.4	AB	97.7 [50]	93.1–102.4	A	96.3 [158]	94.7–97.9	A
Condtruction	–*	–	–	–*	–	–	–*	–	–
Manufacturing	92.5 [458]	90.5–94.5	B	92.9 [324]	91.2–94.5	AB	91.8 [401]	90.6–93.1	B
Protective service	–*	–	–	–*	–	–	–*	–	–
Mechanics and repairers	–*	–	–	–*	–	–	–*	–	–
Other occupations	86.9 [2861]	86.1–87.7	A	92.0 [1914]	91.0–93.0	B	89.3 [1376]	88.2–90.5	C
All occupations	87.6 [3423]	86.7–88.5	A	92.2 [2321]	91.2–93.3	AB	90.4 [1953]	89.7–91.2	BC

*NCHS recommends a minimum sample size of 30 for reporting; any statistics based on sample size <30 was not reported in this table.
**SI: Significance Indicator; means with the same letter are not significantly different.
§[N]: sample size (unwighted raw data).

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