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Anthropometry of industrial populations

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Industrial anthropometric data were collected from workers in various manufacturing industries in the mid-western United States: 384 males and 124 females participated during the period from 1984 through 1991. Eleven length dimensions, weight, and age were assessed at the worksites. Descriptions and statistical analyses of the industrial anthropometric data are summarized and compared to other civilian and military anthropometric data. Significant differences between these populations exist in abdominal dimensions and weight. These differences were also observed to vary with age. These industrial anthropometric data can be used in the design of industrial workplaces and equipment as well as for use with biomechanical models.

1. Introduction

Historically, in the United States of America, a number of anthropometric surveys have been conducted which characterize various special populations such as aviators or military personnel. However, anthropometric data of industrial populations have not been well documented. Nonetheless, from an ergonomic standpoint there is a need to incorporate this information into the design of the workplace.

There have been several large scale surveys of civilian populations. First, O'Brien and Shelton (1941) measured 59 body dimensions from 10 042 white civilian women for garment sizing and pattern construction purposes. Later, the National Center for Health Statistics conducted the Health Examination Survey (HES, Stoudt *et al.* 1965) on a non-institutional civilian population which included 20 anthropometric measurements from 3091 men and 3581 women from 1960 to 1962. Finally, the National Center for Health Statistics conducted the Health and Nutrition Examination Survey (HANES, Abraham *et al.* 1979) of 13 645 persons and sampled civilian heights and weights from 1971 to 1974.

Military anthropometric data have also been collected via large scale surveys. The first major US Air Force anthropometric survey (NASA 1024, 1978) was conducted in 1965 by the Aerospace Medical Research Laboratories. One hundred and fifty-seven body dimensions and grip strength were measured in a population of 3869 subjects. In 1966, the anthropometric data from 6682 Army soldiers and 4095 Navy Enlisted Men were collected from seventy body dimensions (NASA 1024, 1978). Second, a major survey (NASA 1024, 1978) of flying personnel was conducted in 1967. This study included 186 dimensions and grip strength from 2420 male officers on active flying status. In addition, 137 body dimensions were measured on 1905 US Air Force women. Recently, a comprehensive anthropometric survey (Gorden *et al.*

1989) was conducted on 1774 men and 2208 women in the US Army representing the age categories and ethnic groups proportionally during the period from 1987 to 1988. Apparently, military anthropometric data are more current and comprehensive than civilian data. Hence, these data have been often used for biomechanical modelling purposes as well as to design industrial equipment and workplaces.

There exists a need to describe accurately key anthropometric characteristics of the industrial worker. Anthropometric data are one of the key ingredients needed to correctly design workplaces and equipment for the worker. Anthropometric data are also needed to properly assess the loading imposed on workers' joints during the performance of work. In particular, many biomechanical lifting models use anthropometric data to interpret the nature of loadings occurring on the spine during lifting. However, many critical dimensions of workers trunk characteristics are unknown or are believed to deviate significantly from existing military data.

Industrial anthropometric data are rare. The Eastman Kodak Company (1983) reported the anthropometric measurement of 43 body dimensions from 50 to 100 women and 100 to 150 men, which represent a relatively small sample size compared to the previously mentioned civilian and military databases. During the period from 1984 through 1991, the Biodynamics Laboratory at The Ohio State University has been collecting anthropometric data from industrial workers from various manufacturing industries in the mid-western United States. Three hundred and eighty-four males and 125 females have been selected randomly and measured at the work sites. Twelve body dimensions and age were examined including weight, heights, limb lengths, and trunk dimensions. The purpose of this report was to summarize this anthropometric data.

The industrial data are also compared across both civilian and military data to determine the existence of any unique anthropometric characteristics in this industrial population.

2. Method

2.1. *Definitions of measurements*

Definitions and techniques of measurement correspond to the guidelines in NASA 1024 (1978). All length measurements were made with an anthropometer. Circumference dimensions were performed with a tape measure. Bony landmarks corresponded with those described in NASA 1024. However, two new measurements (elbow height and trunk length) used for workplace design and biomechanical modelling were also defined. Four OSU Biodynamics Laboratory data collection personnel were trained to collect the anthropometric data discussed. All measurements were made with the subject standing. The anthropometric definitions used in this study are summarized below:

1. weight*—the weight measured wearing light clothes;
2. stature*—the height measured wearing working shoes;
3. shoulder height (SHD HT)* (acromial height)—the height of the acromion;
4. elbow height*—the height from the floor to the bottom of the elbow when the subject is standing with the elbow positioned in a 90 degrees flexed angle;

*Measured with the subject wearing light clothing and shoes.

5. upper arm length (denoted as UARM LGT) (shoulder–elbow length)—the vertical distance from acromion to the bottom of elbow, measured with the elbow bent 90 degrees and the lower arm held horizontally;
6. lower arm length (denoted as LARM LGT) (forearm–hand length)—the distance from the posterior part of elbow to the tip of the longest finger measured with the elbow flexed at a 90 degree angle;
7. trunk length (TRK LGT) (spine length)—the distance from the lumbar-sacral joint (L5/S1) to top of the first cervical vertebrae while the subject is standing erect;
8. abdominal breadth (AB BRDTH)*—the breadth of the abdomen measured at the level of belly button;
9. abdominal depth (AB DPTH)*—the depth of the abdomen measured at the level of belly button;
10. abdominal circumference (AB CRC)*—the circumference of the abdomen at the level of belly button;
11. leg length (denoted as LEG LGT)* (trochanteric height)—the height from the floor to the top of greater trochanter;
12. lower leg length (denoted as LLEG LGT)* (patella bottom height)—the height from the floor to the bottom edge of the kneecap.

The definitions of weight and stature are somewhat different between our industrial study and military studies because the military study measured essentially the nude weight and height.

2.2. *Data base comparisons*

In order to compare anthropometric characteristics among the different populations, comparison tables were constructed. Compatibility of the data across the surveys was examined based on the definition and measuring technique. Adjustments for clothing and shoes were made by subtracting an adjustment factor from the means and percentile values of industrial data. The amount of adjustment in the measurement was derived from Eastman Kodak (1983) when applicable. The OSU Biodynamics Laboratory took the liberty of making such an adjustment where there was no precedent. The estimated adjustment of measurement for clothing and shoes are as follows:

- 2·5 cm (1 in) for height reflecting the shoe height for males[1]
- 1·5 cm (0·6 in) for height reflecting the shoe height for females[2]
- 0·8 cm (0·3 in) for breadths reflecting the clothes[1]
- 1·5 cm (0·6 in) for circumference reflecting the clothes[2]
- 2·0 lb for the weight of a pair of shoes[2]
- 1·0 lb for the clothing[2]

2.3. *Statistical analyses*

Descriptive statistics were summarized in terms of mean, standard deviation and percentile values. The normality of the data distribution was examined and controlled for outliers. Statistical parameters were computed from the male and

[1]Correction factor suggested by Kodak Company.
[2]Correction factor suggested by the OSU Biodynamics Laboratory.

Table 1A. Industrial anthropometry for total industrial population measured by OSU Biodynamics Lab (1984–1991).

	Total population (509 subjects) Mean	(SD)	Percentiles 5th	50th	95th
AGE	38·21	(10·00)	22·0	38·0	54·0
WEIGHT (lb)*	174·68	(37·20)	120·0	172·5	240·0
STATURE (cm)*	174·36	(9·27)	158·4	175·1	188·0
SHD HT*	144·35	(8·58)	130·4	144·7	157·3
ELB HT*	108·24	(6·42)	97·4	108·3	118·6
UARM LGT	35·90	(2·71)	31·5	36·1	40·0
LARM LGT	47·21	(3·36)	41·6	47·7	52·0
TRK LGT	54·69	(4·12)	47·4	55·0	61·1
AB BRDTH*	31·08	(4·25)	25·0	30·8	38·0
AB DPTH*	25·00	(4·45)	17·5	23·7	32·5
AB CRC*	92·13	(13·80)	71·1	91·5	115·8
LEG LGT*	93·89	(6·48)	83·3	93·6	103·6
LLEG LGT*	48·42	(3·86)	42·4	48·5	54·8

*Measured with subjects wearing light clothing and shoes.

Table 1B. Industrial anthropometry for male industrial population measured by OSU Biodynamics Lab (1984–1991).

	Male population (384 subjects) Mean	(SD)	Percentiles 5th	50th	95th
AGE	37·71	(9·82)	22·0	38·0	55·0
WEIGHT (lb)*	185·27	(34·08)	140·0	180·0	249·0
HEIGHT (cm)*	177·82	(7·25)	167·0	177·8	189·2
SHD HT*	147·63	(6·90)	136·7	147·8	158·4
ELB HT*	110·28	(5·65)	101·5	110·2	119·3
UARM LGT	36·72	(2·32)	32·8	36·6	40·3
LARM LGT	48·50	(2·51)	44·7	48·5	52·5
TRK LGT	56·18	(3·29)	51·0	56·0	61·4
AB BRDTH*	32·20	(3·89)	27·0	31·9	38·2
AB DPTH*	25·00	(4·45)	19·0	24·2	32·9
AB CRC*	95·24	(12·88)	76·5	94·4	117·0
LEG LGT*	95·97	(5·73)	86·8	96·1	104·4
LLEG LGT*	49·66	(3·32)	44·0	49·6	55·1

*Measured with subjects wearing light clothing and shoes.

female populations as well as total population by using computerized statistical analysis software (SAS).

In addition, t-statistics was used to determine whether there were any statistically significant differences between the industrial data and military data. This analysis was based on the assumption that two samples came from the same population with normal distributions.

3. Results

Descriptive statistics of the industrial anthropometric data base are summarized in tables 1A, 1B and 1C. Tables 2A, 2B and 3 show summary comparisons between

Table 1C. Industrial anthropometry for female industrial population measured by OSU Biodynamics Lab (1984–1991).

	Female population (125 subjects) Mean	(SD)	Percentiles 5th	50th	95th
AGE	39·74	(10·44)	25·0	39·0	58·0
WEIGHT (lb)*	142·24	(25·92)	105·0	141·5	195·0
HEIGHT (cm)*	163·71	(6·21)	153·4	163·5	174·3
SHD HT*	135·40	(5·95)	126·0	135·0	145·0
ELB HT*	102·34	(4·52)	95·1	102·0	109·8
UARM LGT	33·28	(1·92)	30·4	33·0	36·9
LARM LGT	43·69	(2·83)	40·3	43·6	49·0
TRK LGT	50·64	(3·37)	44·6	50·5	56·5
AB BRDTH*	28·06	(3·69)	22·6	27·8	35·2
AB DPTH*	21·84	(4·30)	15·7	21·6	30·0
AB CRC*	82·64	(12·11)	67·2	81·0	105·0
LEG LGT*	88·25	(4·83)	80·7	87·9	95·5
LLEG LGT*	45·05	(3·18)	40·3	44·7	50·0

*Measured with subjects wearing light clothing and shoes.

Table 2A. Comparison table of mean values for male data (numbers in parentheses refer to reference number in list of references).

	Industry* (1984–91)	Army (5) (1987–88)	Air Force (3) (1967–68)	Kodak (4) (1983)	HANES (1) (1971–74)
AGE	37·7	26·2	30·0	—	—
WEIGHT (lb)	182·3	173·0	173·6	180·4	172·0
HEIGHT (cm)	175·3	175·6	177·3	175·0	175·3
SHD HT	145·1	144·3	145·2	143·9	—
ELB HT	107·8	107·3	—	—	—
UARM LGT	36·7	36·9	36·0	37·0	—
LARM LGT	48·5	48·4	48·0	—	—
TRK LGT	56·2	—	—	—	—
AB BRDTH	31·4	30·9	28·6	—	—
AB DPTH	24·2	22·6	22·3	—	—
AB CRC	93·7	86·2	87·6	—	—
LEG LGT	93·5	92·8	94·0	—	—
LLEG LGT	47·2	—	46·7	—	—

*Effect of clothing and shoes is subtracted according to the correction factors described in this report.

major surveys for males and females respectively. The results of *t*-tests comparing the industrial and US Army data are summarized in table 4.

4. Discussion

In this study, industrial anthropometric data were compared with other surveys to identify the unique anthropometric characteristics of the industrial population. This study permits us to quantify the magnitude of the differences between these populations. T-tests indicated significant differences particularly in weight and abdominal dimensions between the male industrial and Army data. There were no significant differences between the industrial and Army data for the female weight

Table 2B. Comparison table of mean values for female data (numbers in parentheses refer to reference number in list of references).

	Industry* (1984–91)	Army (5) (1987–88)	Air Force (3) (1967–68)	Kodak (4) (1983)	HANES (1) (1971–74)
AGE	39·7	27·2	23·4	—	—
WEIGHT (lb)	139·2	136·7	127·3	143·3	143·0
HEIGHT (cm)	162·2	162·9	162·1	162·0	161·5
SHD HT	133·9	133·4	131·9	133·4	—
ELB HT	100·8	101·5	—	—	—
UARM LGT	33·3	33·6	33·3	33·8	—
LARM LGT	43·7	44·3	42·4	—	—
TRK LGT	50·6	—	—	—	—
AB BRDTH	27·3	29·0	24·1	—	—
AB DPTH	21·0	20·4	17·0	—	—
AB CRC	81·1	79·2	67·2	—	—
LEG LGT	85·8	86·2	82·7	—	—
LLEG LGT	42·6	—	42·0	—	—

*Effect of clothing and shoes is subtracted according to the correction factors described in this report.

Table 3. Comparison table of percentile values.

	Male				Female			
	Industry*		Army		Industry*		Army	
	5th	95th	5th	95th	5th	95th	5th	95th
AGE	22·0	55·0	18·4	36·1	25·0	58·0	18·3	37·2
WEIGHT (lb)	140·0	249·0	135·8	216·2	105·0	195·0	109·4	169·7
HEIGHT (cm)	167·0	189·2	164·7	186·7	153·4	174·3	152·8	173·7
SHD HT	136·7	158·4	134·2	154·6	126·0	145·0	124·1	143·2
UARM LGT	32·8	40·3	34·2	39·9	30·4	36·9	30·8	36·5
LARM LGT	44·7	52·5	44·8	52·4	40·3	49·0	40·6	48·3
AB BRDTH	27·0	38·2	26·5	36·0	22·6	35·2	24·9	34·2
AB DPTH	19·0	32·9	19·0	27·3	15·7	30·0	17·0	25·1
AB CRC	76·5	117·0	73·3	101·6	67·2	105·0	67·6	94·6
LEG LGT	86·8	104·4	85·3	100·9	80·7	95·5	78·9	93·8

*Effect of clothing and shoes is subtracted according to the correction factors described in this report.

measure. Other length dimension data showed no significant differences between the two female populations.

Differences in variability of body dimensions were also delineated in this study. The central tendency characteristics of the military data represent a good approximation of linear dimensions in the industrial population. However, variability in weight and abdominal dimensions was greater in the industrial population compared to the Army population for both men and women. For example, an industrial worker of 95th percentile weight is much heavier than the US Army soldier at the same percentile value. However, 5th percentile female industrial workers are slightly lighter than US Army women of the same percentile.

These differences in abdominal dimensions and weight variability have particular

Table 4. *T*-statistics: comparison between industry and Army data.

	Male	Female
AGE	31·88***	18·76***
WEIGHT	6·39**	1·43
HEIGHT	−0·69	−1·24
SHD HT	2·39*	1·00
UARM LGT	−1·73	−1·84
LARM LGT	0·72	−2·71**
AB BRDTH	2·66**	−5·25***
AB DPTH	9·79***	2·65**
AB CRC	14·42***	2·46*
LEG LGT	2·23*	−0·83

*Significant at $p<0{\cdot}05$ (critical $|t|=1{\cdot}960$)
**Significant at $p<0{\cdot}01$ (critical $|t|=2{\cdot}576$)
***Significant at $p<0{\cdot}001$ (critical $|t|=3{\cdot}291$)
'−' indicates that industrial measurement was below that of the Army population.

relevance to biomechanical modelling of the trunk used in lifting models. Many models use both of these dimensions as well as our newly defined trunk length dimension to estimate trunk mass and trunk centre of gravity. Furthermore, abdominal dimensions are also used to estimate muscle cross-sectional area used in biomechanical models. Hence increased anthropometric variability can result in larger variability in the magnitude of loads experienced by the spine.

It should also be noted that there is a significant difference in age distributions between the industrial data and the comparative data. This age difference may explain the differences in abdominal dimensions and weight distributions. Because of this variability, adoption of military anthropometric data for workplace design purposes may not be an appropriate means to accommodate some portions of the industrial population, especially for weight or trunk dimensions. Therefore, the use of this industrial anthropometry is recommended in order to provide appropriate dimensional information which may be used for equipment and workplace design purpose in industry.

5. Conclusion

In this study, twelve anthropometric measurements and age were summarized in an industrial population. New dimensions important for biomechanical modelling such as trunk length (spine length) and elbow height (standing elbow rest height) were also included. Comparisons of data characteristics were made among the industrial population and previous surveys to identify the unique characteristic of this industrial population. The results indicated significant differences in weight and abdominal dimensions between the industry and US Army populations. The difference was more pronounced in the male population than the female population. Variability of weight and abdominal dimensions was also greater in the male population than the female population. This information could be used for the design of the industrial workplace and equipment.

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