A Study of Female Mexican Anthropometric Measures Useful for Workstation Design in Light Manufacturing Facilities

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As more and more manufacturing is moved to Mexico, the need for anthropometric data describing the Mexican working population becomes more pronounced. The purpose of this study was to obtain data on 21 anthropometric measures that could readily be used to design workplaces in light manufacturing operations. Eighty-seven females, representing 26% of the plant's employees, were sampled. Measurements were made with the shoes on. The mean stature (height) and elbow heights of this sample were 156 cm and 97 cm. Another recently published survey of female factory workers near the U.S. border included 12 anthropometric dimensions. Five of the dimensions were measured in both studies. Hand lengths were nearly identical; however, the 2 to 3 cm differences in the heights measured in the current study are consistent with the incorporation of the footwear in the current measurements. Thus, this study adds to the growing database that can be used when designing these light manufacturing jobs in Mexico.

Keywords: anthropometric design, anthropometry, ergonomics, Mexico, workstation design

Grandjean,[1] in his opening address at the NATO symposium on anthropometry and biomechanics, pointed out that "postural efforts" can be minimized by matching workplace dimensions to the body size of the operator. When these dimensions are mismatched, workers are forced into postures that require sustained static contractions and, consequently, fatigue. This article addresses the anthropometric issues arising as more and more manufacturing is being performed in Mexico. Many of these operations are transplants from other parts of the world and use processes and machinery designed for non-Mexican employees. As a result, many of the new jobs in Mexico do not take into account the anthropometric characteristics of the Mexican population. To make matters worse, the engineers in these facilities are faced with the dilemma that only limited anthropometric data describing the characteristics of the Mexican population are available.[2] Thus, the purpose of this article is to present additional anthropometric data describing the female component of the Mexican work force.

METHODS AND MATERIALS

Sample

Eighty-seven females between the ages of 16 and 40 years were sampled. All were employees at an electric motor manufacturing facility in Reynossa, Mexico, in 1998. Only women were included in this sample because at the time of this survey the plant employed 330 people, 95% of whom were female. Employees were sampled from both the day and evening shifts. Although the facility from which the sample was obtained was on the border between the United States and Mexico, workers were reported by the management to have come from throughout the country for these desirable jobs. Thus, the sample was not limited to a regional segment of the population.

TABLE I. Definitions of the Anthropometric Dimensions Measured

Measurement	Measurement Posture/Clothing	Definition[A]
Stature, shod	standing, in shoes	height of the top of the head (805)
Eye height, shod	standing, in shoes	distance from floor to center of pupil
Acromial height, shod	standing, in shoes	height of the acromion above the floor (23)
Elbow rest height standing, shod	standing, in shoes	distance from floor to underside of elbow with elbow flexed 90°
Iliocristale height, shod	standing, in shoes	distance between floor and the highest point on the iliac crest
Eye height, comfortably seated	seated relaxed with no back support, dressed	vertical distance from the examination table to the center of pupil
Acromial height, comfortably seated	seated relaxed with no back support, dressed	height of the acromion above the sitting surface (25)
Elbow rest height, comfortably seated	seated relaxed with no back support, dressed	height of the bottom of the tip of the elbow above the sitting surface (312) measured with the arm flexed 90°
Thigh clearance, seated	seated, dressed	height of the highest point of the thigh above the sitting surface (856)
Thumb-tip reach	standing, bare arm	distance from the wall to the tip of the thumb measured with the subject's shoulders against the wall, her arm extended forward, and her index finger touching the tip of her thumb (867)
Arm reach from wall	standing, dressed	distance from the wall to the tip of the middle finger measured with the subject's shoulders against the wall, her hand and arm extended forward (80)
Buttock to popliteal length	seated, dressed	horizontal distance from the rearmost surface of the buttock to the back of the lower leg (200)
Buttock knee length	seated, dressed	horizontal distance from the rearmost surface of the buttock to the front of the kneecap (194)
Popliteal height, shod	seated, in shoes, dressed	height of the underside of the upper leg above the footrest surface (678)
Forearm knuckle length	elbow flexed 90°, bare arm	horizontal distance from the rearmost part of the elbow with the arm bent 90° to the knuckle of the middle finger when the subject clenched her fist
Hand length	standing, bare hand	distance from the base of the hand to the tip of the middle finger measured along the long axis of the hand (420)
Waist depth, at umbilicus	standing, dressed	depth of the trunk at the level of the umbilicus
Chest depth, at substernale	standing, dressed	depth of the trunk at the level of the substernale
Waist breadth	standing, dressed	width of the trunk at the level of the umbilicus
Grip strength	standing, elbow flexed 90°	power grip measured on a Jamar Dynamometer with a 5-cm handle width

[A]Most of the definitions were obtained from NASA reference publication 1024. Where these were used the definition number from the NASA publication is given in parentheses. Where measurements were made on only one side of the body, the right side was measured.

Apparatus

All length measurements were obtained using a GPM anthropometer (Seritex Inc., East Rutherford, N.J.). Maximum grip strength was measured using a Jamar Dynamometer with the handle width set to 5 cm. Weight was measured using a physician's scale located in the office of the plant's nurse.

Procedure

Data were obtained for each of the measures defined in Table I. Where the dimensions measured were consistent with those summarized by NASA,[3] the dimension number has been provided. In addition, each participant was weighed. Work smocks were removed prior to measurement to facilitate location of bony landmarks, but street clothes and shoes were worn as the measurements were made. Shoes were included because this facility has no policy regarding the type or characteristics of the employees' footwear. Because the footwear is not controlled and the footwear impacts how people interface with the workplace—in particular, the height of the eyes, shoulders, and elbows, and leg clearances—measurements were taken with the shoes on. For similar reasons the participants were not asked to disrobe. Although it is difficult to characterize the street clothes, as they were variable from one individual to the next, they tended to be lightweight material, due in part to the temperate climate. The thickest material encountered in the sample was the denim used in the jeans worn by a small number of participants.

To remove interobserver reliability problems, only one of the authors (S.L.) collected the data. The nurses in the facility assisted by explaining the purpose of the survey and by providing instructions in Spanish to the employees during the measurement process. Once the data were obtained, simple checks were performed

TABLE II. Statistics and Percentiles Describing the Sample of 87 Female Employees in a Mexican Light Manufacturing Facility

Measurement	Mean	SD	Percentiles							
			Min	Max	2.5	5th	10th	90th	95th	97.5
Stature, shod (cm)	156.3	5.2	145.5	173.5	146.1	147.7	149.6	163.0	164.9	166.5
Eye height, shod (cm)	145.1	4.9	132.0	161.0	135.4	137.0	138.8	151.5	153.3	154.8
Acromial height, shod (cm)	129.5	4.7	119.1	147.3	120.2	121.7	123.4	135.5	137.2	138.7
Elbow rest height standing, shod (cm)	97.2	4.1	88.5	110.2	89.3	90.5	92.0	102.5	103.9	105.2
Iliocristale height, shod (cm)	92.9	4.2	85.0	105.0	84.5	85.9	87.4	98.3	99.9	101.2
Eye height, comfortably seated (cm)	70.0	2.9	63.9	80.0	64.3	65.2	66.3	73.8	74.9	75.8
Acromial height, comfortably seated (cm)	54.1	3.0	47.8	62.5	48.2	49.2	50.2	57.9	59.0	59.9
Elbow rest height, comfortably seated (cm)	22.4	3.0	14.1	32.2	16.5	17.5	18.5	26.2	27.3	28.2
Thigh clearance, seated (cm)	13.5	1.7	8.9	17.9	10.2	10.8	11.4	15.6	16.2	16.7
Thumb-tip reach (cm)	53.1	2.9	42.5	60.0	47.4	48.3	49.4	56.8	57.9	58.8
Arm reach from wall (cm)	64.3	3.0	56.0	71.9	58.5	59.4	60.5	68.1	69.2	70.2
Buttock to popliteal length (cm)	43.9	2.8	38.5	53.0	38.4	39.3	40.3	47.6	48.6	49.5
Buttock knee length (cm)	55.3	3.2	47.3	64.4	49.1	50.1	51.2	59.4	60.6	61.6
Popliteal height, shod (cm)	36.6	2.8	31.5	46.3	31.3	32.1	33.1	40.2	41.2	42.0
Forearm knuckle length (cm)	31.5	1.8	27.3	37.0	28.1	28.6	29.3	33.8	34.4	35.0
Hand length (cm)	16.8	0.8	14.5	18.6	15.2	15.5	15.8	17.9	18.2	18.5
Waist depth, at umbilicus (cm)	21.8	4.7	14.0	40.7	12.5	14.0	15.7	27.8	29.5	31.0
Chest depth, at substernale (cm)	21.9	3.9	16.0	37.3	14.2	15.4	16.9	26.9	28.4	29.6
Waist breadth (cm)	27.5	4.3	19.4	43.0	19.1	20.5	22.0	33.0	34.5	35.9
Grip strength (kg)	25.6	4.3	16.0	40.0	17.1	18.5	20.0	31.1	32.7	34.1
Weight (kg)	62.5	15.3	35.5	132.0	32.5	37.3	42.8	82.1	87.6	92.4
Age (years)	23.4	5.5	16	40	12.6	14.3	16.3	30.5	32.5	34.2

to evaluate data quality. In addition to reviewing the minimum and maximum values for each dimension for plausibility, differences between selected measures were evaluated to ensure there were no reading or recording errors. Finally, descriptive statistics, including means and key percentiles used in anthropometric design, were calculated. The percentiles presented in this article were calculated by adding and subtracting the product of the standard deviation and normal distribution Z values for the desired percentiles to or from the mean value for each measurement.

RESULTS

Table II summarizes the anthropometric characteristics of the female sample. The mean stature from this sample was 156 cm with shoes on. The authors would like to draw attention to the average eye, elbow, and waist (iliac crest) heights, 145 cm, 97 cm, and 93 cm, respectively, as these are perhaps the most frequently used measurements in adjusting working heights. When employees are seated, the data describing the seated eye and elbow

TABLE III. Intercorrelations Between the Measurements

Dimension	1	2	3	4	5	6	7	8	9	10
1	1.000									
2	0.966	1.000								
3	0.950	0.944	1.000							
4	0.890	0.879	0.921	1.000						
5	0.878	0.886	0.878	0.799	1.000					
6	0.603	0.602	0.583	0.623	0.414	1.000				
7	0.595	0.579	0.652	0.691	0.440	0.799	1.000			
8	0.235	0.241	0.300	0.439	0.083	0.677	0.768	1.000		
9	0.252	0.225	0.291	0.375	0.194	0.359	0.405	0.346	1.000	
10	0.567	0.572	0.585	0.445	0.580	0.209	0.281	−0.117	0.027	1.000
11	0.661	0.666	0.669	0.556	0.680	0.308	0.358	−0.090	0.089	0.866
12	0.456	0.430	0.466	0.421	0.499	0.164	0.207	0.022	0.292	0.281
13	0.497	0.452	0.513	0.491	0.497	0.234	0.288	0.096	0.497	0.258
14	0.661	0.662	0.630	0.543	0.709	0.116	0.109	−0.216	−0.154	0.486
15	0.575	0.568	0.619	0.592	0.647	0.367	0.411	0.123	0.479	0.507
16	0.552	0.559	0.580	0.521	0.588	0.373	0.392	0.043	0.316	0.482
17	0.194	0.160	0.281	0.325	0.158	0.316	0.436	0.398	0.644	−0.059
18	0.167	0.131	0.256	0.301	0.150	0.310	0.453	0.414	0.609	−0.066
19	0.224	0.179	0.289	0.369	0.168	0.351	0.462	0.385	0.731	−0.013
20	0.133	0.148	0.195	0.208	0.163	0.224	0.218	0.079	0.374	0.245
21	0.311	0.273	0.364	0.443	0.241	0.469	0.537	0.506	0.771	−0.028
22	−0.157	−0.196	−0.075	−0.079	−0.207	0.162	0.182	0.234	0.237	−0.086

Note: Measurement numbers are defined in Table I.

TABLE IV. Comparison Between Data Collected in the Current Study With That From Liu et al.

		Current Study		Liu et al. (1999)	
Measurement	Shoes	Mean	SD	Mean	SD
Stature (cm)	yes	156.3	5.2		
	no			153.5	5.8
Eye height (standing)(cm)	yes	145.1	4.9		
	no			142.8	5.9
Elbow rest height (standing)(cm)	yes	97.2	4.1		
	no			95.6	4.0
Hand length (cm)	not relevant	16.8	0.8	16.9	0.9
Weight (kg)	yes	62.5	15.3		
	no			59.3	10.4
Age (years)	not relevant	23.4	5.5	24.2	5.1

heights become important, as does the 90th percentile thigh clearance. Table III provides the intercorrelations between the measures. The correlations ranged between 0.96 (eye height versus stature) to −.01 (buttock to popliteal length versus grip strength). Overall, the best correlations were between the different height and length measures.

DISCUSSION

The data presented here substantially increase the data that are readily available to those designing jobs south of the U.S. border and are consistent with that presented by Lui et al.[2] Given that there is limited overlap in the dimensions sampled, the two studies complement one another nicely. In their study Liu et al.[2] sampled 110 female workers at two Mexican plants in Tijuana. In characterizing their population, these authors reported that the average age of their sample, 24.2 years, was similar to other studies of female Mexican factory workers. This value is very close to the average age of the current sample (23.4 years).

Lui et al.[2] sampled 12 anthropometric dimensions. Of these, 5 dimensions were sampled in both studies. Table IV shows that the best correspondence was with respect to hand size. The data from the height measures differ by between 1.6 and 3 cm. This difference can be accounted for, at least in part, by the inclusion of the participants' footwear in the current measurements. The shoes were included in this study for two reasons. First, the authors wanted data showing what could actually be expected with regard to the sampled anthropometric dimensions out on the plant floor. Thus, these data show how the people came to work, and hence, can be used as is rather than forcing attempts at correction after the fact. Second, there was no prescribed footwear for these workers, so shoe heights were highly variable. It is possible that this variation in footwear would be responsible for the reduced variance in the stature and eye height measures relative to that reported by Liu et al.[2] This would be the case if the shorter individuals elected to wear higher shoes than the taller individuals, in other words, a self-selected "regression toward the mean." Similarly, the only garments that these workers were asked to remove were their work smocks. Although this may introduce error into the measurements, for the most part the lightweight clothing would have a very small impact on the data given the accuracy that can reasonably be expected from anthropometric

TABLE III. Extended.

11	12	13	14	15	16	17	18	19	20	21	22
1.000											
0.336	1.000										
0.336	0.883	1.000									
0.569	0.195	0.136	1.000								
0.620	0.449	0.564	0.333	1.000							
0.671	0.269	0.377	0.384	0.699	1.000						
0.011	0.432	0.592	−0.162	0.430	0.196	1.000					
0.006	0.395	0.540	−0.143	0.400	0.243	0.937	1.000				
0.093	0.418	0.571	−0.163	0.475	0.286	0.906	0.825	1.000			
0.324	−0.013	0.083	0.051	0.456	0.455	0.159	0.247	0.254	1.000		
0.081	0.420	0.612	−0.149	0.519	0.326	0.915	0.893	0.903	0.280	1.000	
−0.108	−0.009	0.068	−0.305	−0.009	0.049	0.361	0.376	0.338	0.082	0.281	1.000

measurements. Moreover, the authors believe that the inclusion of clothing in this survey removes the need to estimate its impact when designing workplaces to fit this population.

When the women in this study are compared with a sample of the female American work force,[4] it is clear that there are significant differences between these populations. For example, the average values for female stature, shoulder height, and elbow height in the north central United States (163.7 cm, 135.4 cm, and 102.3 cm)[2] are very close to the 90th percentile values for this Mexican population. It should be noted that both samples were obtained with the participants wearing shoes, although the author's observation is that there was considerably less variation in the shoe heights in the U.S population. More important, these differences highlight the need to readjust the lines in manufacturing operations transplanted from the United States.

Clearly, one limitation of the data from this study and from Liu et al.'s study is that it describes only the female segment of the population. Obviously, the data have limited use in Mexican facilities that employ a greater percentage of males. Nevertheless, these data add 15 more dimensions to those currently available describing this working female population and may be very applicable to the design of light manufacturing operations in Mexico that have attracted primarily females employees.[2]

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