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LEVEL II

A COMPARISON OF MALE AND FEMALE BODY SIZES AND PROPORTIONS

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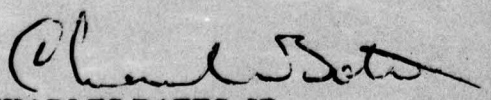

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There has been, in the past few years, an increase in the diversity of occupational positions filled by women in the Air Force and the other military branches. As the opportunities increase, the workplace designer is faced more and more frequently with the problem of accommodating the female. Accompanying this problem is a need for documentation of true differences in body size and proportions between Air Force men and women. This report is an initial attempt at fulfilling this need.

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20. ABSTRACT (cont'd)

Utilizing the 1977 Army survey, because it is the only survey in which both military males and females were measured at the same time and place, by the same measurers, and using the same measuring techniques and instruments, this study investigates two basic assumptions about the relationship between male and female body size and proportions. The first is the assumption that a female body size can be represented by scaling down the male body. The second is the assumption that females and males of approximately equal body weight and stature are approximately equal in all other proportions. The results of these investigations serve to pinpoint where differences occur and the magnitude of those differences. This should aid in determining the designs or changes in designs which will be necessary to accommodate the female.

PREFACE

This study was conducted under contract F33615-78-C-0508 with the Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, Ohio, in response to the requirements of Project 7184, "Man-Machine Integration Technology," Task 71841203, "Engineering Anthropology for Life Support." Mr. Charles E. Clauser, Crew Station Integration Branch, Aerospace Medical Research Laboratory, acted as contract monitor. Consultation with Mr. Clauser and Dr. Kenneth W. Kennedy, also of Crew Station Integration Branch, helped focus the needs of this report with respect to design.

The primary source of data in this analysis was the 1977 survey of U.S. Army women initiated by Mr. Robert M. White of the Natick Research and Development Command, Natick, Massachusetts. During preliminary discussions centered on the design of this survey, it was Mr. Clauser who recognized the unique opportunity for collecting comparable male data and Mr. White who made possible the incorporation of this valuable adjunct study into the female survey design.

The authors are grateful to Dr. Melvin Warrick who reviewed the manuscript with his usual painstaking care and to Ms. Ilse Tebbetts and Ms. Jane Reese for editing the report and preparing it for publication.

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INTRODUCTION

There has been, over the past few years, a radical increase in the number and types of occupational roles which women fill in the U.S. Air Force. While women formerly served almost exclusively in nursing and other health related specialties, and in a variety of clerical roles, today most Air Force occupations, including the piloting of high performance aircraft, are assignable to and, indeed, occupied by Air Force women.

This means that all types of work stations must be evaluated to determine if they require redesigning to accommodate the dimensional differences of female users. This study is undertaken to investigate the differences in body proportions between Air Force men and women and to determine whether the current assumptions about these relationships are valid.

Designers, faced with the need for developing composite male/female workplace layouts, have made certain, perhaps inevitable, assumptions. One such assumption is that, for purposes of design, the female can be considered as a scaled-down male. The second assumption is based on the observation that the military female's 50th percentile height and weight correspond relatively well with 5th percentile male height and weight values, and that the 95th percentile female height-weights correspond with the male 50th percentile values. Therefore, it is often assumed that a design which accommodates the 5th and 50th percentile male body sizes will also accommodate the 50th and 95th percentile female body sizes or, put another way, that males and females of approximately equal stature and weight are more or less equal to each other in body size. As far as we know, these two assumptions represent the only existing bases for transposing male body size values to female values. The purpose of our comparative analysis is to test these assumptions and to establish thereby whether or not Eve can usefully be regarded as a fractional multiple of Adam's rib.

USAF male and female data are available but we hesitate to use these data because differences observed may be due to subtle differences in landmark interpretations and measuring techniques, possibly obscuring or exaggerating real differences where they exist. Instead, we utilized the anthropometric data obtained from the 1977 U.S. Army women's survey in which some 69 body dimensions were measured on a sample of 1331 women and an additional 73 dimensions were obtained from a series of subsamples. Prior to the completion of the survey, 287 Army men were also measured for some of the same dimensions by members of the same measuring team. Thus, we have measurements of Army men and women obtained by the same personnel using identical equipment and techniques. These data provide us with a unique source of measurements for comparative purposes.

THE SOURCE DATA

During the 1977 survey, 1331 Army women were measured at four military posts. About a quarter of this group (344) were officers, chiefly lieutenants and captains, and three quarters (987) were enlisted women, mostly in the lowest ranks. The median age was approximately 22.5 years with about 85% of the women falling between 18 and 28. The full age distribution is shown in Table 1. Distribution of sample by race appears in Table 2: 75.2% of the sample were Whites, 22.9% were Blacks, and 1.9% were Orientals. No attempt was made to identify Chicanos separately from Whites.

TABLE 1

DISTRIBUTION OF SAMPLE BY AGE

Age	n	%	CUM %
50-60	3	0.2	100.1
45-50	12	0.9	99.9
40-45	13	1.0	99.0
35-40	26	2.0	98.0
30-35	74	5.6	96.0
28-30	67	5.0	90.4
26-28	104	7.8	85.4
24-26	188	14.1	77.6
23-24	103	7.7	63.5
22-23	138	10.4	55.8
21-22	102	7.7	45.4
20-21	108	8.1	37.7
19-20	156	11.7	29.6
18-19	219	16.5	17.9
17-18	18	1.4	1.4
Total	1331	100.1	

Mean Age	Standard Deviation
23.1	5.4

Percentiles	
99th	45.7
95th	33.6
90th	29.3
75th	25.1
50th	22.0
25th	19.1
10th	18.0
5th	17.7
1st	17.2

TABLE 2

DISTRIBUTION OF SAMPLE BY RACE

	Officers		Enlisted		Total	
	n	%*	n	%*	n	%*
Whites	302	89.1	687	70.3	989	75.2
Blacks	29	8.6	273	27.9	302	22.9
Orientals	8	2.4	17	1.7	25	1.9
Not Identified	5		10		15	
Total	344	100.1	987	99.9	1331	100.0

* Percent of those identified.

Job classifications of the enlisted women fall into three groups of approximately equal size: clerical workers (typists and clerks); medical personnel (laboratory technicians, nurses' aides, X-ray, dental, pharmacy, operating room, and medical records specialists or technicians); and all others. Of the occupations which make up this third group, only the military police (n=67) constitute a subgroup as large as 5% of the sample.

While a handful of subjects had been in the Army for over 20 years, close to two-thirds had been in for less than a year and about one-third for less than two months.

The 287 subjects who made up the male sample were a very homogeneous group in terms of age, rank, and length of service. One hundred ninety-one men or 67% were Whites, 90 or 31% Blacks, and 6 or 2% were Oriental. With a single exception, they were trainees most of whom had been in the Army less than a month. The mean age was close to 19 years. It has been established that while women attain full stature at approximately 17, the average male does not attain full stature even at age 19 (Roche and Davila, 1972). However, in most cases the additional growth in men is less than one centimeter so we chose to disregard this factor in our study.

A basic series of variables, designated as core measurements, and a supplementary group of dimensions known as traditional measurements, were taken on the women's sample. These are listed in Tables 3 and 4.

Measuring techniques, except as they were affected by clothing, were the same in both the men's and women's surveys, and each member of the measuring team in the men's survey made only those measurements she had previously made in the women's survey.

The women's core and the traditional subseries measurements were made with the subjects wearing panties and bras. It had

TABLE 3

1977 ARMY WOMEN'S SURVEY: CORE MEASUREMENTS;
MALE MEASUREMENTS INDICATED BY X

	Female	Male
1.	Stature	X
2.	Acromiale Height	
3.	Axilla Height	X
4.	Bustpoint Ht (Chest Ht)	X
5.	Waist Height	X
6.	Crotch Height	
7.	Buttock Height	X
8.	Chest Breadth	
9.	Waist Breadth	
10.	Hip Breadth	
11.	Bust Depth (Chest Depth)	X
12.	Waist Depth	X
13.	Sitting Height	X
14.	Eye Height	X
15.	Knee Height	X
16.	Popliteal Height	X
17.	Shoulder-Elbow Lgth	X
18.	Elbow-Fingertip Lgth	X
19.	Bideltoid Breadth	
20.	Buttock-Knee Lgth	X
21.	Head Circumference	X
22.	Neck Circumference	
23.	Head Length	X
24.	Head Breadth	X
25.	Hand Circumference	X
26.	Hand Breadth	X
27.	Hand Length	X
28.	Palm Length	X
29.	Hip Circumference	X
30.	Upper Thigh Circ	
31.	Knee Circ	
32.	Calf Circ	X
33.	Ankle Circ	X
34.	Heel-Ankle Circ	X
35.	Instep Circ	

	Female	Male
36.	Foot Circumference	X
37.	Heel Breadth	
38.	Knee Height	
39.	Calf Height	
40.	Ankle Height	
41.	Sphyrion Height	X
42.	Foot Length	X
43.	Instep Length	X
44.	Foot Breadth	X
45.	Weight	X
46.	Arm Circ at Scye	
47.	Biceps Circ, Flexed	X
48.	Elbow Circ, Flexed	
49.	Forearm Circ, Flexed	
50.	Wrist Circumference	
51.	Shoulder Length	
52.	Neck to Bustpoint	
53.	Sleeve Inseam	X
54.	Sleeve Outseam	X
55.	Axilla to Waist Level	
56.	Shoulder Circ	X
57.	Chest Circ at Scye	
58.	Bust Circ (Chest Circ)	X
59.	Chest Circ Below Bust	
60.	Waist Circumference	X
61.	Interscye Front	X
62.	Waist Front	X
63.	Interscye Back	X
64.	Waist Back	X
65.	Back Curvature, Bust Level (Chest Level)	X
66.	Back Curvature, Waist Level	X
67.	Back Curvature, Hip Level	X
68.	Vertical Trunk Circ	
69.	Crotch Length	

TABLE 4

1977 ARMY WOMEN'S SURVEY: TRADITIONAL ANTHROPOMETRY;
MALE MEASUREMENTS INDICATED BY X

Female	Male
1. Cervicale Height	
2. Suprasternale Ht	X
3. Substernale Ht	X
4. Elbow Height	X
5. Acromion-Radiale Lgth	X
6. Radiale-Stylion Lgth	X
7. Elbow to Center of Grip	X
8. Elbow Rest Height	
9. Thigh Clearance Ht	
10. Biacromial Breadth	X
11. Abdominal-Extension Depth	
12. Abdominal-Extension Brdth	
13. Thigh-to-Thigh Breadth	
14. Bispinous Breadth	
15. Knuckle Height	X
16. Gluteal Furrow Height	X
17. Trochanteric Height	
18. Tibiale Height	X
19. Axillary Arm Circ	
20. Biceps Circ, Relaxed	X
21. Forearm Circ, Relaxed	
22. Waist Circ (Omphalion)	X
23. Vertical Trunk Circ (Seated)	
24. Hip Circ (Seated)	
25. Skinfold: Triceps	
26. Skinfold: Biceps	
27. Skinfold: Subscapular	
28. Skinfold: Suprailiac	

been anticipated that these measurements would be made in the men's survey with the subjects wearing swimming trunks, but neither swimming nor gym trunks were available in adequate numbers. As a result, the men were measured wearing fatigue pants and underpants and several measurements which had been planned for inclusion in the men's series were dropped because the measurers found it impossible to accurately locate landmarks such as trochanterion, or anterior superior iliac spines. Other measurements, particularly weight, buttock height, buttock-knee length, back curvature-hip level, and hip circumference may have been affected by the clothing. Fatigue pants typically weigh about one kilogram and the summary data statistics of the mean and percentile weights have been adjusted by subtracting this amount. The effects of clothing on the other measurements were judged to be within the accuracy of repeated measurements.

A total of 56 body dimensions were judged to be comparable on the male and female series and were of sufficient diversity as to type of measurement to provide for meaningful comparison of body size and proportionality of the male and female series.

THE COMPARISONS

SCALING DOWN

Our initial step was to compare the summary statistics (mean and 50th%ile) of the total male and total female samples to examine the validity of the assumption that a female is a scaled-down male. Table 5 lists the variable names, the male and female values, their differences, and their differences as a percent of the male value (Δ%). It can be seen from a quick scan of the data that female values are higher than male values for three dimensions--chest depth, hip circumference, and back curvature at hip. Thus, the assumption under scrutiny already begins to spring leaks. For these dimensions, the female does not represent a scaled-down male but would more reasonably be a scaled-up male. It is possible, of course, that these particular dimensions may not be important to a given design and that a designer may choose to overlook them. The next step, then, is to examine the relationship of the other female dimensions with their male counterparts to determine whether female values differ with sufficient consistency to produce a female model by scaling down a male.

To scale down, a designer must calculate the percent difference value for some dimension--probably stature--and scale down the other variables accordingly. If the designer used mean stature, which has a percent deviation (Δ%) of -6.38, then the other variables would have to be scaled down by -6.38% of their respective male mean values. If the Δ%'s of the other variables are similar to the Δ% of stature, then the process will produce a female who realistically represents a scaled-down male. If, on the other hand, the Δ%'s of the other variables are both statistically significant from the Δ% of stature and meaningfully different for practical purposes, then the process will result in a rather questionable "female."

Statistical significance must be determined by the investigator, based on an evaluation of the data. The investigator sets a critical limit of difference which is the greatest value he or she will accept as representing a possible sampling error. Any value beyond the selected limit then represents a real or "statistically significant" difference. We are interested, however, in those differences which would be both statistically significant and of practical significance in design. Our choice for such a value was a plus or minus one percent difference. One percent of the male stature, for example, is 1.74 centimeters and one percent of eye height sitting is 0.77 centimeters--differences which can be meaningful in terms of workplace design. In the early 70's, for instance, differences of this magnitude resulted in a change of Air Force specifications for cockpit design increasing the seat-reference-point-to-cockpit-eyeline distance by 0.5 inch (Kennedy, 1972).

Tabulated in Table 6 are those dimensions that are more than +1Δ% or less than -1Δ% from -6.38%, the difference between male

TABLE 5

A COMPARISON BETWEEN MALE AND FEMALE MEAN AND 50TH PERCENTILE VALUES U.S. ARMY 1977*

Variable	Male $\bar{X}$	Female $\bar{X}$	$\Delta\bar{X}$	$\Delta\%\bar{X}$	Male 50%ile	Female 50%ile	Δ 50th%ile	Δ% 50th%ile	Male n	Female n
1. Weight	153.82	132.22	-21.60	-14.08	149.1	131.3	-17.8	-11.94	287	1331
2. Stature	174.07	162.96	-11.11	-6.38	174.1	162.8	-11.3	-6.49	287	1331
3. Axilla Ht	131.24	123.25	-7.99	-6.09	131.3	123.1	-8.2	-6.25	287	1331
4. Suprasternale Ht	142.70	132.62	-10.08	-7.06	142.7	132.7	-10.0	-7.01	287	255
5. Chest Ht	127.43	118.30	-9.13	-7.17	127.5	118.2	-9.3	-7.29	287	1331
6. Substernale Ht	122.57	113.90	-8.70	-7.06	122.6	113.9	-8.7	-7.07	287	255
7. Elbow Ht	109.40	102.56	-6.84	-6.25	109.4	102.4	-7.0	-6.40	287	255
8. Knuckle Ht	75.51	70.99	-4.52	-5.99	75.5	70.9	-4.6	-6.50	287	255
9. Waist Ht	104.12	101.39	-2.73	-2.62	104.1	101.2	-2.9	-2.79	287	1331
10. Buttock Ht	89.41	83.80	-5.61	-6.27	89.5	83.6	-5.9	-6.59	287	1331
11. Gluteal Furrow Ht	80.37	74.13	-5.84	-7.27	80.3	73.9	-6.4	-7.97	287	255
12. Tibiale Ht	48.31	44.05	-4.26	-8.82	48.4	44.0	-4.4	-9.09	283	255
13. Acromion-Radiale L	33.74	30.85	-2.89	-8.57	33.7	30.9	-2.8	-8.31	287	255
14. Radiale-Stylion L	26.84	24.37	-2.47	-9.20	26.8	24.3	-2.5	-9.33	287	255
15. Sitting Ht	89.34	85.08	-4.26	-4.77	89.3	85.2	-4.1	-4.59	287	1331
16. Eye Ht Sitting	77.42	73.64	-3.78	-4.88	77.3	73.8	-3.5	-4.53	287	1331
17. Shoulder-Elbow L	36.32	33.56	-2.76	-7.60	36.3	33.5	-2.8	-7.71	287	1331
18. Elbow Grip Lgth	34.97	32.25	-2.72	-7.78	35.0	32.1	-2.9	-8.29	287	255
19. Elbow-Fingertip L	47.77	43.52	-4.25	-8.90	47.7	43.4	-4.3	-9.01	287	1331
20. Knee Ht Sitting	55.10	50.99	-4.11	-7.46	55.1	50.9	-4.2	-7.62	287	1331
21. Popliteal Ht	44.27	41.68	-2.59	-5.85	44.3	41.6	-2.7	-6.09	287	1331
22. Buttock-Knee Lgth	60.78	57.85	-2.93	-4.82	60.8	57.7	-3.1	-5.10	287	1331
23. Chest Depth	21.68	22.92	+1.24	+5.72	21.4	22.7	+1.3	+6.07	287	1331
24. Waist Depth	20.29	18.29	-2.00	-9.86	19.8	18.0	-1.8	-9.09	287	1331
25. Biacromial Br	39.46	35.71	-3.75	-9.50	39.5	35.7	-3.8	-9.62	287	255
26. Shoulder Circ	110.92	100.39	-10.53	-9.49	110.6	100.2	-10.4	-9.40	287	1331
27. Chest Circ	92.90	88.21	-4.69	-5.05	91.9	87.9	-4.0	-5.35	287	1331
28. Waist Circ	78.68	71.01	-7.67	-9.75	76.9	70.1	-6.8	-8.84	287	1331
29. Waist Circ Omphal	78.87	76.21	-2.66	-3.37	76.5	75.0	-1.5	-1.96	287	255
30. Hip Circ	95.14	95.52	+0.38	+0.40	94.1	95.3	+1.2	+1.28	287	1331
31. Biceps Circ Relxd	29.16	25.89	-3.27	-11.21	29.0	25.9	-3.1	-10.69	287	255
32. Biceps Circ Flxd	31.38	26.87	-4.51	-14.37	31.3	26.8	-4.5	-14.38	287	1331
33. Calf Circ	35.83	35.09	-0.74	-2.07	35.6	35.1	-0.5	-1.40	287	1331
34. Ankle Circ	21.71	20.73	-0.98	-4.51	21.7	20.7	-1.0	-4.61	287	1331
35. Interscye (Back)	41.02	37.82	-3.20	-7.80	41.0	37.9	-3.1	-0.76	287	1331
36. Interscye (Front)	36.67	33.17	-3.50	-9.54	36.6	33.1	-3.5	-9.56	287	1331
37. Back Curv, Chest	45.17	41.97	-3.20	-7.08	44.7	41.8	-2.9	-6.49	287	1331
38. Back Curv, Waist	38.96	35.31	-3.65	-9.37	38.2	34.9	-3.3	-8.64	287	1331
39. Back Curv, Hip	46.57	47.51	+0.94	+2.02	46.0	47.3	+1.3	+2.83	287	1331
40. Waist Back Lgth	44.90	40.85	-4.05	-9.02	44.9	40.7	-4.2	-9.35	287	1331
41. Waist Front Lgth	41.05	36.74	-4.76	-11.60	41.0	36.5	-4.5	-10.98	287	1331
42. Sleeve Inseam Lgth	48.26	45.05	-3.21	-6.65	48.2	44.9	-3.3	-6.85	287	1331
43. Sleeve Outseam Lgt	58.77	53.80	-4.97	-8.46	58.6	53.6	-5.0	-8.53	287	1331
44. Head Circ	56.01	54.92	-1.09	-1.95	56.1	54.8	-1.3	-2.32	287	1331
45. Head Br	15.06	14.61	-0.45	-2.99	15.1	14.6	-0.5	-3.31	287	1331
46. Head Lgth	19.47	18.71	-0.76	-3.90	19.5	18.7	-0.8	-4.10	287	1331
47. Palm Lgth	10.75	9.88	-0.87	-8.09	10.8	9.9	-0.9	-8.33	287	1331
48. Hand Br	8.92	7.82	-1.10	-12.33	8.9	7.8	-1.1	-12.36	287	1331
49. Hand Circ	21.11	18.45	-2.66	-12.60	21.1	18.4	-2.7	-12.79	287	1331
50. Hand Lgth	19.00	17.44	-1.55	-8.16	19.0	17.4	-1.6	-8.42	287	1331
51. Instep Lgth	19.71	17.85	-1.86	-9.44	19.7	17.8	-1.9	-9.64	286	1331
52. Foot Lgth	26.76	24.32	-2.44	-9.12	26.8	24.3	-2.5	-9.33	286	1331
53. Heel-Ankle Circ	34.02	30.79	-3.23	-9.49	33.9	30.7	-3.2	-9.44	287	1331
54. Foot Br	9.92	8.87	-1.05	-10.58	9.9	8.9	-1.0	-10.10	286	1331
55. Foot Circ	25.15	22.61	-2.54	-10.10	25.1	22.6	-2.5	-9.96	287	1331
56. Sphyrion Ht	7.38	6.46	-0.92	-12.47	7.4	6.5	-0.9	-12.16	286	1331

*Weight in pounds; all other dimensions in centimeters.

TABLE 6

A COMPARISON OF SCALED DOWN MALE VALUES WITH ACTUAL FEMALE VALUES

Variable	Male $\bar{X}$	Female $\bar{X}$	$\Delta\%\bar{X}$ (+ indicates female larger)	Δ from $-6.38\Delta\%$	Values in cm
1. Weight	153.82	132.22	-14.08	-7.70	-11.84
2. Stature	174.07	162.96	-6.38		
3. Axilla Ht**	131.24	123.25	-6.09	--	--
4. Suprasternale Ht**	142.70	132.62	-7.06	--	--
5. Chest Ht**	127.43	118.30	-7.17	--	--
6. Substernale Ht**	122.57	113.90	-7.06	--	--
7. Elbow Ht**	109.40	102.56	-6.25	--	--
8. Knuckle Ht**	75.51	70.99	-5.99	--	--
9. Waist Ht	104.12	101.39	-2.62	+3.76	+3.91
10. Buttock Ht**	89.41	83.80	-6.27	--	--
11. Gluteal Furrow Ht**	80.37	74.13	-7.27	--	--
12. Tibiale Ht	48.31	44.05	-8.82	-2.44	-1.18
13. Acromion-Radiale L	33.74	30.85	-8.57	-2.19	-0.74
14. Radiale-Stylion L	26.84	24.37	-9.20	-2.82	-0.76
15. Sitting Ht	89.34	85.08	-4.77	+1.61	+1.44
16. Eye Ht Sitting	77.42	73.64	-4.88	+1.50	+1.16
17. Shoulder-Elbow L	36.32	33.56	-7.60	-1.22	-0.44
18. Elbow Grip Lgth	34.97	32.25	-7.78	-1.40	-0.49
19. Elbow-Fingertip L	47.77	43.52	-8.90	-2.52	-1.20
20. Knee Ht Sitting	55.10	50.99	-7.46	-1.08	-0.60
21. Popliteal Ht**	44.27	41.68	-5.85	--	--
22. Buttock-Knee Lgth	60.78	57.85	-4.82	-1.56	-0.95
23. Chest Depth	21.68	22.92	+5.72	+12.10	+2.62
24. Waist Depth	20.29	18.29	-9.86	-3.48	-0.71
25. Biacromial Br	39.46	35.71	-9.50	-2.12	-1.23
26. Shoulder Circ	110.92	100.39	-9.49	-3.11	-3.45
27. Chest Circ	92.90	88.21	-5.05	+1.33	+1.24
28. Waist Circ	78.68	71.01	-9.75	-3.37	-2.65
29. Waist Circ Omphal	78.87	76.21	-3.37	+3.01	+2.37
30. Hip Circ	95.14	95.52	+0.40	+6.78	+6.45
31. Biceps Circ Relxd	29.16	25.89	-11.21	-4.83	-1.41
32. Biceps Circ Flxd	31.38	26.87	-14.37	-7.99	-2.51
33. Calf Circ	35.83	35.09	-2.07	+4.31	+1.54
34. Ankle Circ	21.71	20.73	-4.51	+1.87	+0.41
35. Interscye (Back)	41.02	37.82	-7.80	-1.42	-0.58
36. Interscye (Front)	36.67	33.17	-9.54	-3.16	-1.16
37. Back Curv, Chest**	45.17	41.97	-7.08	--	--
38. Back Curv, Waist	38.96	35.31	-9.37	-2.99	-1.16
39. Back Curv, Hip	46.57	47.51	+2.02	+8.40	+3.91
40. Waist Back Lgth	44.90	40.85	-9.02	-2.64	-3.13
41. Waist Front Lgth	41.05	36.74	-11.60	-5.22	-2.14
42. Sleeve Inseam L**	48.26	45.05	-6.65	--	--
43. Sleeve Outseam L	58.77	53.80	-8.46	-2.08	-1.22
44. Head Circ	56.01	54.92	-1.95	+4.43	+2.48
45. Head Breadth	15.06	14.61	-2.99	+3.39	+0.51
46. Head Lgth	19.47	18.71	-3.90	+2.48	+0.48
47. Palm Lgth	10.75	9.88	-8.09	-1.71	-0.18
48. Hand Br	8.92	7.82	-12.33	-5.95	-0.53
49. Hand Circ	21.11	18.45	-12.60	-6.22	-1.31
50. Hand Lgth	19.00	17.44	-8.16	-1.78	-0.34
51. Instep Lgth	19.71	17.85	-9.44	-3.06	-0.60
52. Foot Lgth	26.76	24.32	-9.12	-2.74	-0.73
53. Heel-Ankle Circ	34.02	30.79	-9.49	-3.11	-1.06
54. Foot Br	9.92	8.87	-10.58	-4.20	-0.42
55. Foot Circ	25.15	22.61	-10.10	-3.72	-0.94
56. Sphyrion Ht	7.38	6.46	-12.47	-6.09	-0.45

* Weight in pounds; all other dimensions in centimeters.
**No significant difference.

and female mean stature and the basic unit by which we are trying to "scale down" the male. The third column lists the percent differences (Δ%) by which women are smaller (or, in three cases, larger) than men. The fourth column shows the percent by which these differences deviate from -6.38%. In the fifth column, these percent deviations are translated into actual amounts. Thus, while female stature is 6.38% less than male stature, female sitting height is only 4.77% less (column 3). This is a differentiation of 1.61% (fourth column) or 1.44 cm (fifth column) from the basic scaling-down figure of 6.38% indicating that the scaled down male model would be 1.44 centimeters too short in sitting height to accurately represent the mean female.

Whether or not these deviations are important will depend on the design involved. A 1.44 centimeter difference in sitting height may not significantly influence the position of the head on the back of a seat, but may well affect visual capabilities. While Table 6 shows clearly that 44 of the 46 variables cannot be scaled down consistent with the base figure, the discrepancies represented by amounts outside the range of ±1Δ% may not be sufficiently bothersome to worry about in some design problems. A designer may wish to eliminate those dimensions which have values which are more than +2Δ% or less than -2Δ% or, from a somewhat different point of view, may concern himself only with those values which will result in a discrepancy of more than one centimeter.

The variables with the most discrepant values are those associated with body tissue (mostly depths, breadths, and circumferences) and dimensions of the head, hands, and feet. Heights and length dimensions are more similar to stature although some of them (chiefly arm, leg, hand and foot dimensions) are outside the ±1Δ% range and would be outside a ±2Δ%. Waist height, waist back, and waist front appear to deviate markedly from stature. We suspect that this may be due to measurement differences. The waist landmark in this survey was located at the "natural" waist level, which is the level defined by the subject. It is very likely that the females located this point at a higher level than the male. We suspect, therefore, that the differences reflected by these data are not wholly attributable to anatomical differences.

While these results indicate that the female does not represent a scaled-down male for nearly 80% of the dimensions under study, nevertheless scaling down can be a practical solution for limited design problems. For example, if a workspace designer is only concerned that chair height is low enough for the feet to touch the floor and that the table is high enough to clear the thigh, then scaling down popliteal height/knee height sitting will produce a validly usable result. In general, the dimensions which are the most likely "scale-downables" are heights and lengths; however, they must be carefully selected to be sure they will not be importantly affected by body tissue. Among those which the designer should approach with caution are such variables as sitting height and buttock-knee length which involve the buttock tissue.

It was recognized that some of the differences or similarities between the male and the female values may be masked by their differences in race and age components. We prepared similar comparisons utilizing race and age matched samples, to neutralize possible differences caused by these two factors (see Appendix). Patterns similar to the total sample comparison were found to occur with only minor differences.

PERCENTILE MATCH-UPS

It has been assumed by a number of designers that, for all practical purposes, the 5th percentile male is the equivalent in body size and proportions to the 50th percentile female, and that the 50th percentile male is comparable to the 95th percentile female. These assumptions were based on what was considered to be the relative correspondence of these height and weight percentile values for various male and female samples. In fact, the level of correspondence of these percentile values is not as high as is often supposed (see Table 7, below).

TABLE 7

PERCENTILE VALUES FOR SELECTED MALE-FEMALE SAMPLES*

	50th%ile		95th%ile	
Female	Height	Weight	Height	Weight
USAF'68	162.1	126.1	172.2	156.3
USAW'77	162.8	131.4	173.4	164.3
HEW'62	161.8	130.3	172.0	197.1
Male	**5th%ile**		**50th%ile**	
USAF'67	167.1	140.2	177.3	172.4
Army'66	163.8	126.3	174.5	156.3
HEW'62	164.1	127.4	175.3	166.7

* Weight in pounds; height in centimeters.

Smaller women (below 50th percentile) are often eliminated from consideration altogether by means of height/weight requirements.

In Table 8 we use the 1977 Army data to compare all 56 variables for both percentile match-ups. While the percentile heights of the two groups described in the table are identical, it can be seen that the percentile weight values are considerably different. A study of the data further reveals that males and females differ by less than $\pm$1% for about a quarter of the measured variables and by less than $\pm$2% for half of them. However, for the remaining half of the dimensions, the Δ% is over $\pm$2% and ranges from -20%

TABLE 8

A COMPARISON OF PERCENTILE VALUES BETWEEN MEN AND WOMEN
(Male 5th with Female 50th; Male 50th with Female 95th)
U.S. ARMY 1977*

Variable	Male 5%ile	Female 50%ile	Δ	Δ%	Male 50%ile	Female 95%ile	Δ	Δ%	Male n	Female n
1. Weight	120.2	131.3	-11.1	-9.23	149.1	164.3	+15.2	+10.19	287	1331
2. Stature	162.8	162.8	0.0	0.00	174.1	174.1	0.0	0.00	287	1331
3. Axilla Ht	121.5	123.1	-1.6	-1.32	131.3	132.7	-1.4	-1.07	287	1331
4. Suprasternale	132.6	132.7	-0.1	+0.08	142.7	142.0	+0.7	+0.49	287	255
5. Chest Height	117.9	118.2	-0.3	-0.25	127.5	125.7	1.8	1.41	287	1331
6. Substernale Ht	113.4	113.9	-0.5	-0.47	122.6	122.2	+0.4	+0.33	287	255
7. Radiale Ht	101.0	102.4	-1.4	-1.39	109.4	110.7	-1.3	-1.19	287	255
8. Knuckle Ht	68.8	70.9	-2.1	-3.11	75.5	77.5	-2.0	-2.65	287	255
9. Waist Ht	94.6	101.2	-6.6	-6.98	104.1	110.3	-6.2	-5.96	287	1331
10. Buttock Ht	80.8	83.6	-2.8	-3.47	89.5	91.8	-2.3	-2.57	287	1331
11. Gluteal Furrow	73.3	73.9	-0.6	-0.82	80.3	81.0	-0.7	-0.87	287	255
12. Tibiale Ht	43.5	44.0	-0.5	-1.15	48.4	48.2	+0.2	+0.41	283	255
13. Acromion-Radiale L	30.8	30.9	-0.1	-0.32	33.7	33.4	+0.3	+0.89	287	255
14. Radiale-Stylion	24.4	24.3	+0.1	+0.41	26.8	27.0	-0.2	-0.75	287	255
15. Sitting Ht	83.5	85.2	-1.7	-2.04	89.3	90.8	-1.5	-1.68	287	1331
16. Eye Ht Sitting	72.0	73.8	-1.8	-2.50	77.3	79.1	-1.8	-2.33	287	1331
17. Shoulder-Elbow	33.3	33.5	-0.2	-0.60	36.3	36.6	-0.3	-0.83	287	1331
18. Elbow-Grip Lgth	31.7	32.1	-0.4	-1.26	35.0	35.4	-0.4	-1.14	287	255
19. Elbow-Fingertip L	43.8	43.4	+0.4	+0.91	47.7	47.5	+0.2	+0.42	287	1331
20. Knee Ht Sitting	50.2	50.9	-0.7	-1.39	55.1	55.5	-0.4	-0.73	287	1331
21. Popliteal Ht	39.7	41.6	-1.9	-4.79	44.3	45.7	-1.4	-3.16	287	1331
22. Buttock-Knee Lgth	55.7	57.7	-2.0	-3.59	60.8	63.2	-2.4	-3.95	287	1331
23. Chest Depth	18.9	22.7	-3.8	-20.11	21.4	26.8	-5.4	-25.23	287	1331
24. Waist Depth	17.5	18.0	-0.5	-2.86	19.8	22.3	-2.5	-12.63	287	1331
25. Biacromial Br	36.1	35.7	+0.4	+1.11	39.5	38.3	+1.2	+3.04	287	255
26. Shoulder Circ	101.4	100.2	+1.2	+1.83	110.6	109.4	+1.2	+1.08	287	1331
27. Chest Circ	83.8	87.9	-4.1	-4.89	91.9	99.0	-7.1	-7.73	287	1331
28. Waist Circ	68.8	70.1	-1.3	-1.89	76.9	83.5	-6.6	+8.58	287	1331
29. Waist Circ Omph	68.4	75.0	-6.6	-9.65	76.5	90.9	-14.4	-18.82	287	255
30. Hip Circ	87.3	95.3	-8.0	-9.16	94.1	106.1	-11.9	-12.65	287	1331
31. Biceps Circ Relaxed	24.8	25.9	-1.1	-4.44	29.0	30.3	-1.3	-4.48	287	255
32. Biceps Circ Flexed	27.0	26.8	+0.2	+0.74	31.3	30.7	+0.6	+1.92	287	1331
33. Calf Circ	31.6	35.1	-3.5	-11.08	35.6	39.3	-3.7	-10.39	287	1331
34. Ankle Circ	19.3	20.7	-1.4	-7.25	21.7	22.9	-1.2	-5.53	287	1331
35. Interscye (Back)	36.5	37.9	-1.4	-3.84	41.0	41.7	-0.7	-1.71	287	1331
36. Interscye (Front)	33.5	33.1	+0.4	+1.19	36.6	36.2	+0.4	+1.09	287	1331
37. Back Curv, Chest	40.5	41.8	-1.3	-3.21	44.7	47.4	-2.7	-6.04	287	1331
38. Back Curv, Waist	33.5	34.9	-1.4	-4.18	38.2	41.6	-3.4	-1.01	287	1331
39. Back Curv, Hip	42.4	47.3	-4.9	-11.56	46.0	54.0	-8.0	-17.40	287	1331
40. Waist Back	39.6	40.7	-1.1	-2.78	44.9	45.4	-0.5	-1.11	287	1331
41. Waist Front	36.1	36.5	-0.4	-1.11	41.0	41.4	-0.4	-0.98	287	1331
42. Sleeve Inseam	43.9	44.9	-1.0	-2.28	48.2	49.6	-1.4	-2.90	287	1331
43. Sleeve Outseam	53.8	53.6	+0.2	+0.37	58.6	58.9	-0.3	-0.51	287	1331
44. Head Circ	53.2	54.8	-1.6	-3.01	56.1	57.7	-1.6	-2.85	287	1331
45. Head Breadth	14.2	14.6	-0.4	-2.82	15.1	15.6	-0.5	-3.31	287	1331
46. Head Length	18.3	18.7	-0.4	-2.19	19.5	19.8	-0.3	-1.54	287	1331
47. Palm Length	9.8	9.9	-0.1	-1.02	10.8	10.8	0.0	0.00	287	1331
48. Hand Breadth	8.3	7.8	+0.5	+6.02	8.9	8.5	+0.4	+4.49	287	1331
49. Hand Circ	19.5	18.4	+1.1	+5.64	21.1	19.9	+1.2	+5.69	287	1331
50. Hand Length	17.4	17.4	0.0	0.0	19.0	19.1	-0.1	-0.53	287	1331
51. Instep Length	17.7	17.8	-0.1	-0.56	19.7	19.6	+0.1	+0.51	286	1331
52. Foot Length	24.5	24.3	+0.2	+0.82	26.8	26.5	+0.3	+1.12	286	1331
53. Heel-Ankle Circ	31.3	30.7	+0.6	+1.92	33.9	33.3	+0.6	+1.77	287	1331
54. Foot Breadth	9.0	8.9	+0.1	+1.11	9.9	9.7	+0.2	+2.02	286	1331
55. Foot Circ	23.2	22.6	+0.6	+2.59	25.1	24.5	+0.6	+2.39	287	1331
56. Sphyrion Ht	6.4	6.5	-0.1	-1.56	7.4	7.3	+0.1	+1.35	286	1331

* Weight in pounds; all other dimensions in centimeters.

(chest depth) to +6% (hand breadth). The size and number of these differences appear, in general, so large, as to invalidate any wholesale assumption of male/female correspondence for selected percentiles.

HEIGHT/WEIGHT MATCH-UPS

As shown above, one of the pitfalls of assuming 5th/50th percentile and 50th/95th percentile male/female correspondence is that comparability based on one variable (stature) does not carry with it a similar degree of comparability in weight with all its associated fleshy dimensions. What then, if we went a step further and compared males and females of approximately equal stature and weight? To find an answer to this question we constructed two matched samples from the Army survey. For each of the males, a female of approximately the same stature and weight was drawn. The maximum deviation of our matched pairs did not exceed one centimeter and 2.6 pounds, respectively. Weights of the male subjects were adjusted by subtracting one kilogram from the recorded values to account for the fatigue pants worn during measurement. A total of 204 pairings was achieved with resulting height/weight mean and standard deviations as shown in Table 9.

TABLE 9

HEIGHT AND WEIGHT MEANS AND STANDARD DEVIATIONS OF 204 MATCHED MALE-FEMALE PAIRS*

	Matched Females		*Matched Males*		*Total Female Sample*		*Total Male Sample*	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Height	171.50	5.40	171.57	5.39	162.96	6.52	174.07	6.82
Weight	146.14	15.94	145.52	17.66	132.22	19.16	153.82	24.22

* Values in pounds and centimeters.

The average heights and weights of the matched pairs are seen to fall between those of the individual populations but are somewhat closer to the male than to the female values. The summary statistics for 44 compared variables are given in Table 10.† For each pair the difference between the male's value and the female's value was computed. The mean and standard deviation for all of

† The number of variables compared is reduced from the previously used 56 because only 255 women were measured in the "traditional" series from which the additional 12 measurements were derived and not enough matched pairs could be drawn from this relatively small subseries of women.

TABLE 10

SUMMARY STATISTICS FOR
STATURE-AND-WEIGHT-MATCHED SAMPLES*
U.S. ARMY 1977*

NO.	VARIABLE NAME	MALE MEAN	MALE S.D.	FEMALE MEAN	FEMALE S.D.
1	WEIGHT	145.52	17.66	146.14	15.94
2	STATURE	171.57	5.39	171.50	5.40
3	AXILLA HEIGHT	129.09	4.76	130.13	4.54
4	CHEST HEIGHT	125.42	4.65	125.04	4.81
5	WAIST HEIGHT	102.31	4.75	107.43	4.59
6	BUTTOCK HEIGHT	87.82	4.28	88.84	4.33
7	SITTING HEIGHT	88.37	3.21	88.52	3.29
8	EYE HEIGHT/SITTING	76.56	3.07	76.64	3.12
9	SHOULDER-ELBOW LTH	35.71	1.58	35.36	1.51
10	ELBOW-FINGERTIP LH	47.07	2.22	45.54	1.96
11	KNEE HEIGHT/SIT	54.00	2.51	53.91	2.39
12	POPLITEAL HEIGHT	43.38	2.30	44.26	2.07
13	BUTTOCK-KNEE LNGTH	59.64	2.48	61.11	2.74
14	CHEST DEPTH	21.23	1.66	23.29	1.77
15	WAIST DEPTH	19.75	1.85	18.90	1.97
16	SHOULDER CIRCUMFER	109.39	4.96	102.74	4.71
17	CHEST CIRC	91.30	5.29	89.96	5.36
18	WAIST CIRCUMFERNCE	76.53	6.42	73.12	6.43
19	HIP CIRCUMFERENCE	93.19	4.50	99.20	5.18
20	BICEPS CIRC,FLEXED	30.89	2.34	27.53	1.93
21	CALF CIRCUMFERENCE	35.09	2.29	36.17	2.28
22	ANKLE CIRCUMFERENC	21.35	1.28	21.50	1.10
23	INTERSCYE, BACK	40.50	2.59	38.72	2.35
24	INTERSCYE, FRONT	36.21	1.77	34.20	1.65
25	BACK CURVATURE-CHST	44.42	2.85	42.91	2.52
26	BACK CURVATURE-WAIST	37.87	3.55	36.27	3.13
27	BACK CURVATURE-HIP	45.71	2.51	48.99	3.18
28	WAIST BACK LENGTH	44.20	2.84	42.63	2.82
29	WAIST FRONT LENGTH	40.55	2.84	37.91	2.64
30	SLEEVE INSEAM LGTH	47.48	2.40	47.57	2.38
31	SLEEVE OUTSEAM LTH	57.77	2.80	56.75	2.45
32	HEAD CIRCUMFERENCE	55.80	1.58	55.65	1.69
33	HEAD BREADTH	15.02	.54	14.76	.58
34	HEAD LENTH	19.39	.69	18.99	.64
35	PALM LENGTH	10.62	.54	10.26	.49
36	HAND BREADTH	8.84	.40	8.04	.39
37	HAND CIRCUMFERENCE	20.91	.90	19.00	.86
38	HAND LENGTH	18.77	.92	18.16	.87
39	INSTEP LENGTH	19.41	1.04	18.65	.97
40	FOOT LENGTH	26.38	1.21	25.42	1.21
41	HEEL-ANKLE CIRCUMF	33.54	1.56	32.02	1.42
42	FOOT BREADTH	9.81	.54	9.12	.54
43	FOOT CIRCUMFERENCE	24.89	1.18	23.32	1.20
44	SPHYRION HEIGHT	7.28	.57	6.75	.60

* Weight in pounds; all other values in centimeters; n=204.

the differences are shown in Table 11. It should be emphasized that data shown on Table 11 represent the mean of the differences, not the difference of the means; these values are, in fact, the same but because of rounding off appear to be discrepant. These mean differences (excluding stature and weight) range from a low of -6.65 cm for shoulder circumference to a high of +5.82 cm for hip circumference. This tabulation suggests that the major differences in body proportions, given similar overall body size; relate to the primary sex characteristics; that is, bust and hip development in the women and areas of muscle development (shoulders, biceps, etc.) in the men.

To sift out mean differences which may not be real but, rather, appear as a result of sampling error, we prepared a table with the mean differences accompanied by a type of probability statement (the confidence interval) indicating the amount of difference which might be caused by sampling error (Table 12). Column 1 of Table 12 duplicates column 1 of Table 11, listing the mean differences found between the respective male and female dimensions in the matched sample. Column 2 lists the so-called 99% confidence interval about the mean.* For axilla height, for example, this signifies that although the female is, on the average, 1.35 cm larger than the male counterpart in the sample, the mean difference might, in terms of a probability statement, range from as little as 1.00 (1.35 cm - 0.35 cm) to as much as 1.70 (1.35 + 0.35 cm) larger. The interval of 0.35 represents the difference which might be accounted for by sampling error.

If, as in the case of weight, stature or chest height on Table 12, the value of the confidence interval is larger than the value of the mean difference, then the difference between the male and female is insignificant since all of it might conceivably be caused by sampling error. As can be seen, very few of the differences between variables in this height/weight matched sample are statistically insignificant. Only chest height, sitting height, eye height-sitting, shoulder-elbow length, knee height-sitting, ankle circumference, sleeve inseam length and head circumference can be considered to display no real differences (aside from height and weight which, of course, are the variables by which these samples were matched in the first place).

Up to now we have compared mean values. To further explore the matter, we converted the mean differences and confidence values

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* The confidence interval treats the differences as a distribution and was derived by multiplying the Z value for 99% confidence (2.57) times the standard error of the mean deviation $\left(\frac{SD}{\sqrt{n}}\right)$, n being 204 since there are 204 differences (i.e. subject pairs). The resulting interval indicates that there are 99 chances out of 100 that application of the experiment on an exhaustive scale would yield a mean difference value within that interval.

TABLE 11

SUMMARY STATISTICS FOR THE DIFFERENCES
BETWEEN THE MALE AND THE FEMALE IN EACH PAIR
U.S. Army 1977*
(Positive value indicates female is larger)

NO.	VARIABLE NAME	$\bar{X}\Delta$	S.D.
1	WEIGHT	.10	1.00
2	STATURE	.02	.34
3	AXILLA HEIGHT	+1.35	1.97
4	CHEST HEIGHT	.07	2.68
5	WAIST HEIGHT	+5.49	3.55
6	BUTTOCK HEIGHT	+1.19	3.68
7	SITTING HEIGHT	+.27	3.29
8	EYE HEIGHT/SITTING	+.24	3.21
9	SHOULDER-ELBOW LTH	.22	1.58
10	ELBOW-FINGERTIP LH	1.29	2.32
11	KNEE HEIGHT/SIT	.12	2.02
12	POPLITEAL HEIGHT	+.99	1.85
13	BUTTOCK-KNEE LNGTH	+1.35	2.34
14	CHEST DEPTH	+1.94	1.67
15	WAIST DEPTH	1.12	1.61
16	SHOULDER CIRC	6.65	3.83
17	CHEST CIRC	1.49	4.41
18	WAIST CIRCUMFERNCE	4.01	5.11
19	HIP CIRCUMFERENCE	+5.82	3.70
20	BICEPS CIRC,FLEXED	3.36	1.81
21	CALF CIRCUMFERENCE	+.99	1.80
22	ANKLE CIRC	+.02	1.22
23	INTERSCYE, BACK	1.85	3.13
24	INTERSCYE, FRONT	2.01	1.89
25	BACK CURVATURE-CHST	1.66	2.40
26	BACK CURVATURE-WAIST	1.75	2.98
27	BACK CURVATURE-HIP	+3.23	2.91
28	WAIST BACK LENGTH	1.75	3.51
29	WAIST FRONT LENGTH	2.86	3.23
30	SLEEVE INSEAM LGTH	+.24	2.68
31	SLEEVE OUTSEAM LTH	.84	2.67
32	HEAD CIRCUMFERENCE	.10	2.07
33	HEAD BREADTH	.30	.70
34	HEAD LENGTH	.36	.90
35	PALM LENGTH	.32	.67
36	HAND BREADTH	.80	.46
37	HAND CIRCUMFERENCE	1.97	1.02
38	HAND LENGTH	.55	1.07
39	INSTEP LENGTH	.74	1.12
40	FOOT LENGTH	.91	1.32
41	HEEL-ANKLE CIRC	1.56	1.58
42	FOOT BREADTH	.67	.68
43	FOOT CIRCUMFERENCE	1.59	1.26
44	SPHYRION HEIGHT	.54	.76

* Weight in pounds; all other values in centimeters; n=204.

TABLE 12

MALE/FEMALE DIFFERENCES WITH
99% CONFIDENCE INTERVAL*
(Positive Value Indicates Female is Larger)

Variable Name	$\bar{X}\Delta$	99%C	Variable Name	$\bar{X}\Delta$	99%C
Weight	0.10	±0.17	Interscye Back	1.85	±0.56
Stature	0.02	±0.06	Interscye Front	2.01	±0.34
Axilla Height	+1.35	±0.35	Back Curv Chest	1.66	±0.43
Chest Height	0.07	±0.48	Back Curv Waist	1.75	±0.54
Waist Height	+5.49	±0.64	Back Curv Hip	+3.23	±0.52
Buttock Height	+1.19	±0.70	Waist Back	1.75	±0.63
Sitting Height	+0.27	±0.59	Waist Front	2.86	±0.58
Eye Height Sitting	+0.24	±0.58	Sleeve Inseam Lgth	+0.24	±0.48
Shoulder-Elbow Lgth	0.22	±0.28	Sleeve Outseam Lgth	0.84	±0.48
Elbow-Fingertip Lgth	1.29	±0.42	Head Circumference	0.10	±0.37
Knee Height Sitting	0.12	±0.36	Head Breadth	0.30	±0.13
Popliteal Height	+0.99	±0.33	Head Length	0.36	±0.16
Buttock-Knee Lgth	+1.35	±0.42	Palm Length	0.32	±0.12
Chest Depth	+1.94	±0.30	Hand Breadth	0.80	±0.08
Waist Depth	1.12	±0.33	Hand Circumference	1.97	±0.18
Shoulder Circ	6.65	±0.69	Hand Length	0.55	±0.19
Chest Circ	1.49	±0.79	Instep Length	0.74	±0.20
Waist Circ	4.01	±0.92	Foot Length	0.91	±0.24
Hip Circumference	+5.82	±0.67	Heel-Ankle Circ	1.56	±0.28
Biceps Circ Flxd	3.36	±0.33	Foot Breadth	0.67	±0.12
Calf Circumference	+0.99	±0.32	Foot Circumference	1.59	±0.23
Ankle Circ	+0.02	±0.22	Sphyrion Ht	0.54	±0.14

* Weight in pounds; all other values in centimeters.

into standard deviations and standard score statistics (Table 13). For the designer not highly versed in the intricacies of statistics, the standard deviation indicates the relative distance of values from the mean, as shown in the illustration below.

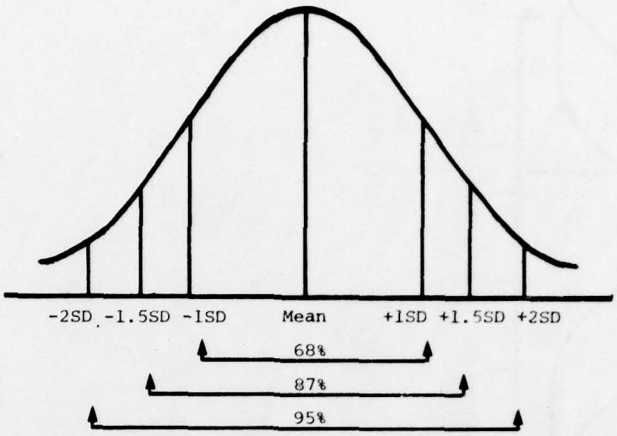

Figure 1. Normal distribution indicating approximate population percentiles with specified standard deviations (SD).

The standard score (or "Z" score) is a value in the distribution expressed as a certain number of standard deviations. We use the standard unit (standard score) because it indicates the size of each value in a distribution with respect to all other values in the distribution. For example, in the male distribution for axilla height (Table 10), one standard deviation equals 4.76 cm. Two standard deviations equal 9.52 cm. If a male had an axilla height of 129.09 + 9.52 cm (the mean plus 2 standard deviations), he would have a standard score of +2.0 standard deviations and he would be larger than approximately 98% of the other males in the distribution. With this measure we can treat the female values as if they were male values and indicate their size with respect to the male distribution.

Figure 2 illustrates pictorially the differences reflected by the standard scores tabulated in Table 13. The female distribution curve is plotted with respect to the male curve for these dimensions. The first plot shows that females with stature and weight equal to male counterparts have an average hand circumference which lies below minus 2 standard deviations, the male 2nd percentile. The second plot shows that these same females have, on the average, a hip circumference greater than one standard deviation above those of the matched males. The third plot shows a small, yet still significant and noticeably different, average buttock height. An insignificantly different dimension is not plotted because no noticeable difference in the curves would occur. The two would nearly overlap.

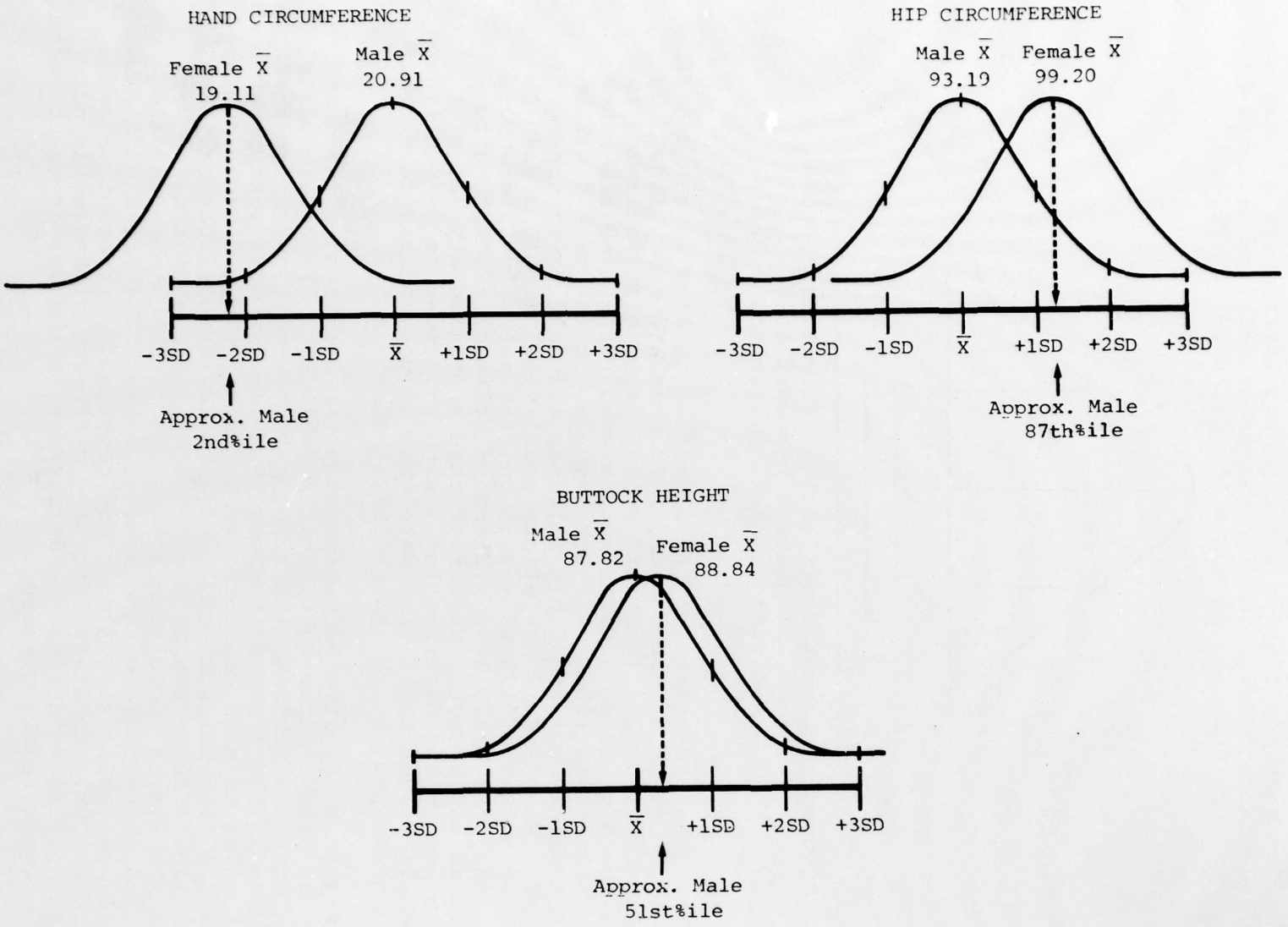

Figure 2. Sample distribution curves.

TABLE 13

MALE-FEMALE DIFFERENCES AS MALE STANDARD SCORE*
(Positive values indicate the female is larger than the male)

Variable Names	$\bar{X}$ Δ Divided by Male SD	99%C Divided by Male SD
SIGNIFICANT		
Hand Circumference	2.19	±0.20
Hand Breadth	2.00	±0.20
Biceps Circ, Flxd	1.44	±0.14
Foot Circumference	1.35	±0.19
Shoulder Circ	1.34	±0.18
Hip Circumference	+1.29	±0.15
Back Curv, Hip	+1.29	±0.21
Foot Breadth	1.24	±0.22
Chest Depth	+1.17	±0.18
Waist Height	+1.16	±0.13
Interscye Front	1.14	±0.19
Waist Front	1.01	±0.20
Heel-Ankle Circ	1.00	±0.18
Sphyrion Height	0.95	±0.25
Foot Length	0.75	±0.20
Instep Length	0.71	±0.19
Interscye Back	0.71	±0.22
Waist Circumference	0.62	±0.14
Waist Back	0.62	±0.22
Waist Depth	0.61	±0.18
Hand Length	0.61	±0.21
Palm Length	0.59	±0.22
Back Curv, Chest	0.58	±0.15
Elbow-Fingertip Lgth	0.58	±0.19
Head Breadth	0.57	±0.30
Buttock-Knee Length	+0.54	±0.17
Head Length	0.52	±0.23
Back Curv, Waist	0.49	±0.15
Popliteal Height	+0.43	±0.14
Calf Circumference	+0.43	±0.14
Sleeve Outseam	0.30	±0.17
Axilla Height	+0.28	±0.07
Chest Circumference	0.28	±0.15
Buttock Height	+0.28	±0.16
INSIGNIFICANT		
Shoulder-Elbow Length	0.14	±0.18
Sleeve Inseam Length	+0.10	±0.20
Sitting Height	+0.08	±0.18

TABLE 13 (cont'd)

INSIGNIFICANT

Variable Names	$\bar{X}$ Δ Divided by Male SD	99%C Divided by Male SD
Eye Height Sitting	+0.08	±0.19
Head Circumference	0.06	±0.23
Knee Height Sitting	0.05	±0.14
Chest Height	0.02	±0.10
Ankle Circumference	+0.02	±0.17
Weight	0.01	±0.01
Stature	0.00	±0.01

* All values are in standard deviations.

It can be seen that -2.19 ±.2 standard deviation for hand circumference and +1.29 ±.15 standard deviation for hip circumference represent a considerable deviance between male and female values. More importantly, it will be noted that the entire distribution shifts along with the mean which suggests that for some items separate sizing systems will be required.

In short, the results indicate that even the female of height and weight equal to a male does not have the same body proportionality. In addition, the female values are in some cases smaller than the male and in other cases larger than the male. It can be seen that marked differences occur in dimensions related to primary sex characteristics and that there are major differences in the hands and feet. The standard scores indicate that many of the female mean values are between ± one and two standard deviations away from the male mean values. The differences at the distal appendages were not unexpected since these dimensions correlate poorly with stature and weight and, therefore, were not well controlled by the selection process. This means that no matter what the average stature and weight of the samples, the hand and foot differences would remain about the same, with the female's much smaller.

Once again it should be noted that if the designer does not feel that the differences between given male and female dimensions are large enough to affect the design, then the male values may be used to represent the female. It should be noted, however, that the greater the number of dimensions used in a model, the larger the discrepancy may become.

CONCLUSION

In this report we have tested the bases on which male body size data have been manipulated to produce comparable female forms, and conclude that the female, for the most part, cannot be adequately represented with male body size data. Furthermore, analysis of the commonly-held assumptions--that the female represents a scaled-down male, and that males and females matched for height and/or weight will be essentially equal in all other dimensions--resulted in findings very similar to each other regarding the comparability of individual dimensions.

On the whole, it was found that height and length dimensions can, in fact, be scaled down with some reliability and also that matched height/weight samples indicate a high degree of similarity between the sexes for these same dimensions. For the designer and model-maker this means that if variables such as knee height or shoulder-elbow length are the key dimensions in the design of a workspace to be occupied by both sexes, then any one of the methods used to represent the female dimensions as some fraction of the male dimensions might work reasonably well.

Among the dimensions which are least reliable, on the other hand, are those involving body tissue which are commonly thought of as being primary sex characteristics. These include such variables as hip circumference, shoulder circumference, biceps circumference/flexed and chest depth, dimensions which designers concerned with seat width or harness assemblies, for example, should view with great wariness. A second category of variables which will not reliably scale down or match up include hand, foot and head dimensions. It should be noted, in addition, that lengths and heights which incorporate body tisue (e.g. axilla height or buttock-knee length) are also somewhat erratic and cannot be counted on with any confidence.

It should be emphasized, in conclusion, that the findings in this report should in no way be construed to mean that designing workplaces and equipment for use by both men and women presents insoluble problems. Rather, it is our contention, based on analysis of the best available data, that traditional approaches to the problem are based on over-simplified and inaccurate understandings of male and female body-size configurations. While more sophisticated approaches to design problems involving heterogeneous populations are the subject of other reports, we would recommend, at the least, a more discriminating application of the male/female data and models currently in use.

APPENDIX

In scaling down male values and comparing them to actual female values, it was recognized that observed differences or similarities might be obscured by differences in race and age of the subject population. To eliminate these factors, we prepared similar comparisons of age- and race-matched subjects.

The total U.S. Army 1977 male population (n=287) was utilized in the matching. A female of the same race and age (to the nearest year) was selected from the Army 1977 female population and matched to each male subject with results as depicted on Table 14.

In the matched sample, the mean difference in stature between males and females was 6.61%, the key value to which we compared all other scaled down differences.

Overall results for the matched sample closely reflected those obtained by comparing the unmatched samples.

TABLE 14

A COMPARISON BETWEEN MALE AND FEMALE MEAN VALUES FOR RACE- AND AGE-MATCHED SAMPLES* (U.S. ARMY 1977)

(Positive value indicates female is larger)

Variable Names	MALE $\bar{X}$	MALE SD	FEMALE $\bar{X}$	FEMALE SD	$\bar{X}\Delta$	$\bar{X}\Delta\%$	$\Delta$from † -6.61$\Delta\%$	cmΔ from -6.61$\Delta\%$
1. Weight	153.8	24.2	130.3	16.4	-23.5	-15.30	-8.69	-13.37 lb
2. Stature	174.1	6.8	162.6	6.8	-11.5	-6.61		
3. Axilla Height	131.2	5.9	123.0	5.9	-8.2	-6.25	--	--
4. Chest Height	127.4	5.7	118.2	5.9	-9.2	-7.22	--	--
5. Waist Height	104.1	5.7	101.4	5.6	-2.7	-2.59	+4.02	+4.18
6. Buttock Height	89.4	5.1	84.3	4.9	-5.1	-5.70	--	--
7. Sitting Height	89.3	3.6	84.3	3.8	-5.0	-5.60	+1.01	+0.90
8. Eye Height Sitting	77.4	3.4	72.8	3.7	-4.6	-5.94	--	--
9. Shoulder-Elbow Lgth	36.3	1.9	33.6	1.9	-2.7	-7.44	--	--
10. Elbow-Fingertip Lgth	47.8	2.5	43.8	2.3	-4.0	-8.37	-1.76	-0.84
11. Knee Height Sitting	55.1	3.0	50.9	2.7	-4.2	-7.62	-1.01	-0.56
12. Popliteal Height	44.3	2.7	41.8	2.5	-2.5	-5.64	--	--
13. Buttock Knee Length	60.8	3.1	57.8	3.0	-3.0	-4.94	+1.67	+1.02
14. Chest Depth	20.3	2.3	22.5	1.9	+2.2	+2.37	+2.98	+1.82
15. Shoulder Circ	110.9	6.1	100.3	5.2	-10.6	-9.56	-2.95	-3.27
16. Chest Circumference	92.9	6.6	87.0	5.8	-5.9	-6.35	--	--
17. Waist Circumference	78.7	8.0	70.3	5.5	-8.4	-10.67	-4.06	-3.20
18. Hip Circumference	95.1	6.0	94.7	5.6	-0.4	-0.42	+6.19	+5.89
19. Biceps Circ, Flxd	31.4	2.7	26.8	2.0	-4.6	-14.65	-8.04	-2.53
20. Waist Depth	20.3	2.3	18.2	1.8	-2.1	-10.31	-3.70	-0.75
21. Calf Circumference	35.8	2.8	35.1	2.2	-0.7	-1.96	+4.65	+1.66
22. Ankle Circumference	21.7	1.4	20.8	1.3	-0.9	-4.15	+2.46	+0.53
23. Interscye Back	41.0	2.8	37.8	2.5	-3.2	-7.80	-1.19	-0.49
24. Interscye Front	36.7	2.0	33.1	1.7	-3.6	-9.81	-3.20	-1.17
25. Back Arc, Bust	45.2	3.4	41.8	2.9	-3.4	-7.52	--	--
26. Back Arc, Waist	39.0	4.3	35.0	2.8	-4.0	-10.26	-3.65	-1.42
27. Back Arc, Hip	46.6	3.1	47.1	3.2	+0.5	+1.07	+7.68	+3.58
28. Waist Back	44.9	3.2	40.7	2.8	-4.2	-9.35	-2.74	-1.23
29. Waist Front	41.0	3.0	36.5	2.6	-4.5	-10.97	-4.36	-1.79
30. Sleeve Inseam	48.3	2.7	45.4	2.8	-2.9	-6.00	--	--
31. Sleeve Outseam	58.8	3.2	53.9	3.3	-4.9	-8.33	-1.72	-0.83
32. Head Circumference	56.0	1.6	54.9	1.7	-1.1	-1.96	+4.65	+2.60
33. Head Breadth	15.1	0.5	14.5	0.5	-0.6	-3.97	+2.64	+0.97
34. Head Length	19.5	0.7	18.7	0.7	-0.8	-4.10	+2.51	+0.49
35. Palm Length	10.8	0.6	9.9	0.5	-0.9	-8.33	-1.72	-0.19
36. Hand Breadth	8.9	0.4	7.9	0.4	-1.0	-11.24	-4.63	-0.41
37. Hand Circumference	21.1	1.0	18.5	0.9	-2.6	-12.32	-5.71	-1.20
38. Hand Length	19.0	1.0	17.5	0.9	-1.5	-7.89	-1.28	-0.24
39. Instep Length	19.7	1.2	17.9	1.0	-1.8	-9.14	-2.53	-0.50
40. Foot Length	26.8	1.3	24.4	1.3	-2.4	-8.96	-2.35	-0.63
41. Heel-Ankle Circ	34.0	1.7	30.9	1.5	-3.1	-9.12	-2.51	-0.85
42. Foot Breadth	9.9	0.6	8.9	0.5	-1.0	-10.10	-3.49	-0.35
43. Foot Circumference	25.2	1.3	22.7	1.2	-2.5	-9.92	-3.31	-0.83
44. Sphyrion Height	7.4	0.6	6.4	0.5	-1.0	-13.51	-6.90	-0.51

* Weight in pounds; all other values in centimeters.
† Only significant differences (exceeding ±1%) are recorded here.

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SUPPLEMENTARY

INFORMATION

7 December 1979

ERRATA SHEET

for

AMRL-TR-79-69, dated July 1979

A COMPARISON OF MALE AND FEMALE
BODY SIZES AND PROPORTIONS

When indicating differences between male and female values, the minus or plus signs strictly serve the purpose of representing the relationship of the quantities, i.e. which is larger. The sign, in actuality, could be either plus or minus depending on which value is subtracted from the other. An effort was made by the authors to manipulate the signs so as to make the relationships clear to the reader and consistent throughout the report; however, this was not completely accomplished.

It was intended that positive values would indicate differences for which the females are larger and negative when the females are smaller. However, in Table 8 on page 15, it is just the reverse. Also in Table 8, two other errors occur: the signs for differences in "suprasternale height" between the 5th percentile male and the 50th percentile female values should both be negative, as should the signs for the differences in "weight" between the 50th percentile male and the 95th percentile female values. By changing these two signs their use will be consistent with the rest of the table.

In Tables 11, 12 and 13 (pages 19, 20, and 23-24, respectively), minus signs were omitted in order that the dimensions for which the females are larger could be easily seen. The absence of the sign indicates the females are smaller than the males.

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