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13. ABSTRACT ***(Maximum 200 Words)***

The object of the research reported here was to evaluate the success of ARNScan versions 7.1 and 7.2, newly developed software for extracting body measurements from 3-D scans. Investigators used traditional methods to measure 123 male and female subjects for 21 dimensions associated with the sizing and design of military clothing. The same subjects were then scanned, and the same or comparable measurements extracted from the 3-D images. A comparison of the results obtained by each method yielded a number of differences. A variety of statistical procedures were then undertaken to establish whether these differences were important or significant; that is, were they large enough to place subjects in different sizes? Differences were tested against three standards: (1) acceptable measurer error established in the 1988 U.S. Army survey (ANSUR), (2) acceptable error estimated by three experienced tailors, and (3) garment grade in traditionally sized dress clothing. ARNScan fared well against the garment grade criterion; it did not do well against the ANSUR standard. The comparison produced mixed results with respect to the tailors' standards. ARNScan is still in the development stage and is currently being refined.

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PREFACE

This document is the final technical report of one of a series of inter-related projects assembled under the title, "Automating Information Extraction From 3-D Scan Data". It is Apparel Research Network project T2P5 of the Design and Development Focus Group.

Because this project was closely related to other projects, it represents the collaboration of many individuals. The author would like to thank Stephen Addleman, Cyberware Laboratory, Inc., for his efforts in guiding the several organizations toward a common goal. Statistician Mary E. Gross, Anthropology Research Project, Inc. conducted the statistical analyses. Ms. Gross also collected the measurement data from the scans, using ARN Scan software. For the repeatability analysis, she was joined by Shirley E. Kristensen and Ann Lisa Piercy who served as data collectors.

The author also wishes to thank Belva M. Hodge, and Ilse O. Tebbetts, both of Anthropology Research Project, for final production and editing, respectively, of the final document.

INTRODUCTION

BACKGROUND

Supplying the U.S. military with properly fitting uniforms and protective items is a billion-dollar business. Much of that dollar value is tied up in inventory. Many military warehouses contain garments in large numbers but poorly distributed with regard to sizes. This often results in a scarcity of popularly-sized garments issued to military personnel while quantities of clothing in seldom-used sizes gather dust. The ability to manage inventories in such a way as to meet current issue needs and anticipated future needs will greatly streamline current operations and provide significant long-term savings.

Measurements of humans are necessary to design clothing, either mass-market or made-to-order, and in a military context, to issue clothing. Traditionally, measurements of humans for clothing applications have been made with a measuring tape. The advent of three-dimensional (3D) scanning technology has opened new possibilities by allowing the rapid collection of human measurement data, as well as the collection of previously unavailable shape data. Scanning technology itself, however, only allows the collection of 3D data points. The computer screen image does not, itself, provide the information needed to correctly issue military garments. Indeed, the visualized image is nothing more than some hundred thousand dots indistinguishable from each other. To extract measurements from the 3D scan data software must be created and tested to verify that the extracted measurements are accurate. This report documents the testing of one 3D measurement extraction software product. The product continues to be in development, so the conclusions documented here are valid as of the software product running in February, 1998.

This work was carried out under the aegis of Project T2P5, jointly conducted by a number of ARN partners, each of whom brings certain specialized expertise to the effort. The project is coordinated by Stephen Addleman of Cyberware Laboratory, Inc., Monterey, CA. Cyberware has provided software integration as well as overall T2P5 coordination. The other partners involved in T2P5 are Beecher Research Company, Clemson Apparel Research, Ohio University, Southern Polytechnic State University, and Anthropology Research Project, Inc. (ARP). This report documents ARP's activities under T2P5. Each of the organizations will prepare final technical reports documenting their own activities and Cyberware will prepare a complete project report.

PROBLEM

There are essentially two measures of success in computer software development: operational success and functional success. Software engineers themselves are generally charged with verifying operational success. That is: Does the product perform without errors? Is it well integrated with other program elements? Does it have a reasonable user interface, etc.? However, the system engineers must often rely on external help to ensure functional success. That is, does the software perform correctly? ARP is acting, here, as a purveyor of the external standards against which the traditional measurements extracted by T2P5 software can be checked.

Unlike steel bars or precision-milled metal parts, the human being is a structure that continuously changes in size and shape. An individual can move many body parts whose shape changes with movement (e.g., the shape of the biceps as the arm is flexed). Even when a person tries to remain motionless, breathing and involuntary muscle reflexes produce continuous movement. These characteristics present difficulties in obtaining accurate measurements regardless of what methods are used to obtain them. Thus, we cannot describe human measurements in traditional terms of absolute accuracy. We can, however, measure the error associated with the measurement of humans. When different techniques are used, comparison of measurement error rates can be used as one criterion for assessing accuracy.

Although the measurement of humans using traditional tools and techniques is subject to the same sources of error as newer techniques, there exist large traditional data bases whose measurement error is known. In the U.S. Army's 1988-1988 Anthropometric Survey (ANSUR), measurement error data were systematically collected throughout the entire year of data collection (Gordon et al., 1989). Because of the large sample size (nearly 9000 men and women), this study has served as a standard against which other data collection efforts can be compared. Because its techniques have been standardized, and were well documented at the time (Clauser et al., 1988) the ANSUR measuring techniques can be used as a reliable benchmark to assess the validity of measurements extracted from 3D scans.

APPROACH

To address the question, "How accurately does the measurement extraction tool gather anthropometric data from 3D scans?," we have chosen to ask a slightly different, but related question: "How closely do measurements taken with the measurement extraction tool resemble measurements taken by traditional anthropometric techniques?" Our approach was to assemble a group of test subjects, and measure them twice—once using traditional anthropometric techniques, and once using a 3D scanner and the measurement extraction tools. We could then compare the extracted measurements with the traditionally measured ones.

When assessing the results of the comparison, another question to address was: "How close is close enough?" In other words, if the extracted measurement were 3mm different from the traditional measurement, would we consider that difference important or significant? For such an assessment, we used three measures: (1) measurement error rates from ANSUR, (2) experienced tailors' judgements about how close a measurement needs to be, and (3) garment grading (*i.e.,* would a measurement error of 3mm put an individual into the wrong sizes).

METHODS

SAMPLING STRATEGY

Sample size can be expressed in terms of statistical power. The greater the power, the more confidence one can have in the results. Statistical power for this type of question (*i.e.*, do the two measurement methods provide similar or distinct results?) is a function of the magnitude of the expected mean differences between the methods, and the dispersion of values around those means. Using chest circumference as a test case, we calculated the power curve for expected differences of ½ inch and 2 inches. A half inch was chosen because that is the figure often given by tailors as their "close enough" value. Two inches was chosen to offer a contrast. The alpha level was set at the traditional 0.05, and the null hypothesis is that there is no difference between the two measurement methods. Statistical power, expressed as a value ranging from 0 to 1, is a measure of confidence in the result. Figures 1 and 2 illustrate clearly that dramatically larger sample sizes are required to detect smaller differences with the same statistical power. This is intuitively true as well. For the purposes of this program, however, it was disappointing because we would have liked to be able to detect differences smaller than ½ inch. Even at relatively low power, say 0.5, hundreds of cases are necessary.

As a practical matter, collecting data on hundreds of individuals is not within the scope, calendar, or budget of this project. It was necessary to establish a reasonable sample size, in terms of our time limitations and budget, and then recognize that the outcome must be seen as constituting results of a pilot study. That said, it should be noted that a much smaller sample size will still give a reliable *indication* of the differences between methods, even if it does not provide statistical proof.

We therefore set out to measure approximately 150 individuals, in a combination of males and females. The sample includes more males than females since our first field test, at the Marine Corps Recruit Depot, San Diego, offered exclusively male subjects. In a sense, however, any human form is equally valid here, because the test is of the method, not of the population we are measuring. We also used data already collected to increase the sample available for analysis. We believe that the final sample size (n = 123) provides sufficient information to indicate whether the Cyberware WB4 scanning system can collect data sufficiently accurate for use in garment manufacturing.

Power as a Function of Sample Size
ANOVA: 2 inch difference

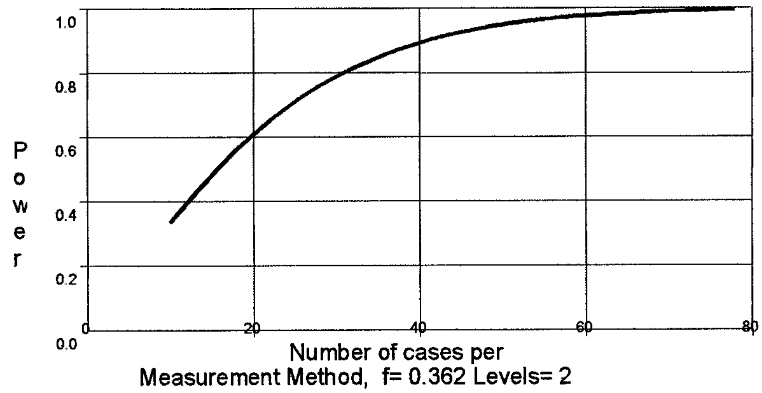

Figure 1

Power as a Function of Sample Size
ANOVA: 2 inch difference

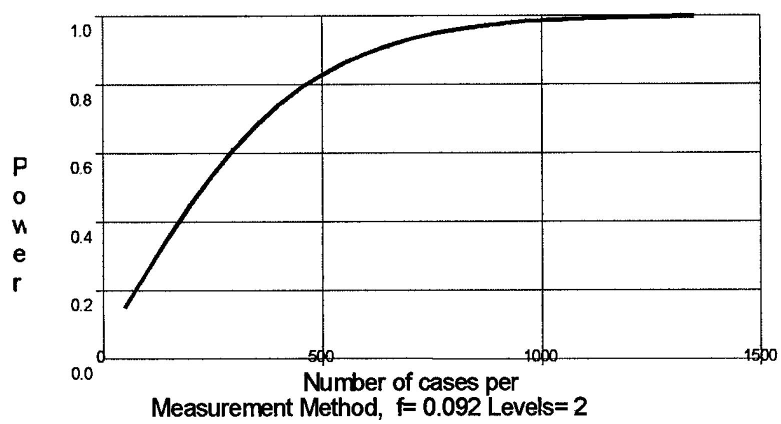

Figure 2

Power as a Function of Sample Size
ANOVA: 1/2 inch difference

DIMENSION SELECTION

One of the key features of 3D scan data is that any number of dimensions can be gathered from the scans at any time after the scan is made. However, where scan measurements are to be compared with traditionally measured dimensions, it was necessary to select dimensions in advance so that all the necessary traditional measurements could be taken while subjects were available. Two primary criteria were used in selecting dimensions for this validation: (1) dimensions should be those known to be challenging for the WB4 scanner, and (2) dimensions should be those critical in creating garment patterns

Dimensions Challenging For The Wb4

Line-of-sight devices, including optical and laser scanners, are challenged by "shadows," where one body part gets in the way of the machine's collecting data from another body part. In this case, the arms may shadow part of the chest and torso. Our test dimensions should therefore include chest, high chest (at scye), waist, and seat circumferences. Depending on head position and the configuration of a person's chin, the chin sometimes can shadow parts of the neck. We included neck circumference in our test. Finally, one leg can shadow the other, so calf circumference was put on the validation list.

Another challenge to the WB4, since its laser is projected on the body in a horizontal beam, is collecting data on areas of the body which curve in or up from the surrounding surfaces. Examples of such areas are the armpit, the crotch, and the bottom of the gluteal furrow. To test measurement extraction in these areas, we included pant inseam (crotch height), gluteal furrow height, and axilla (armpit) height. We also included sleeve inseam, which is measured from the armpit. The final dimension in this class is thigh circumference, which is measured very high in the crotch.

Also challenging the WB4 hardware/software system are dimensions that cover multiple planes or are multi-segmented. Sleeve length (spine to wrist) is a dimension that meets both these criteria, so it was included on the measurement list.

Critical Garment Dimensions

At its January 1997 meeting in Monterey, the T2P5 partners, in conjunction with garment experts Nancy Staples from Clemson Apparel Research, and Mike McLean from Haas Tailoring, created a list of dimensions to be extracted from the whole body scans in order to make the scanning system useful in a clothing context. These were organized into three groups (A, B, and C) denoting relative importance. This allowed the software team to focus their efforts on the most critical areas first. Our validation study include all dimensions on the A list (seen below) plus selected dimensions from the other two lists.

Dimension A List
Chest (Bust) Circumference
Cross Shoulder
Height (Stature)
High Chest Circumference (at Scye)
Seat (Buttock) Circumference
Neck Circumference
Pant Inseam (Crotch Height)
Pant Outseam (Waist Height, Preferred)
Sleeve Length
Sleeve Inseam
Waist (dress trouser) Circumference, Preferred

Note that many of these dimensions were already on our list because they pose particular challenges. The new dimensions added at this step were height, cross shoulder, and pant outseam. We also added biacromial breadth (not on list above), which has the same endpoints as cross shoulder. Ultimately, the ARN software adopted biacromial breadth as its cross shoulder measurement.

The next series of dimensions are those which were judged by our patterning experts to be extremely useful, but not essential. These are listed below.

Dimension B List
Abdominal Girth
Biceps (Flexed) Circumference
Overarm (Shoulder Circumference)
Shoulder Slope
Strap Length
Waist Back Length
Waist Height

For the validation study we added biceps (flexed) circumference, overarm (shoulder) circumference, and waist back length from this list. We did not measure shoulder slope and strap length, because they are subject to relatively high error when measured traditionally. We did not test abdominal girth because it is very similar to the trunk circumferences already on the list, and would add no new information. Waist height is very similar to pant outseam, so it also was not measured. The C List, seen below, contains dimensions that are "nice to have". This list contains dimensions that are generally useful on some types of bodies, but would not be measured on everyone requiring a custom pattern.

Dimension C List
Calf Circumference
Cross Back
Crotch Length
Neck Height Circumference
Shoulder Height
Thigh Circumference

Of these, calf and thigh circumferences had already been selected for validation because they are challenging dimensions. We included shoulder height because, although the dimension itself was on the C List, the identification of the landmark is critical to many patterns. It can also serve to represent neck height as another upper body height. We did not include cross back, because it has a high observer error in traditional measurement. Finally, we included crotch length, because in the traditional method, the tape passes out of sight through the crotch. This is useful for some patterns, and has the potential of being challenging as well. The final list of dimensions for our validation study is seen below. Dimensions marked with an asterisk are those tested in this first round of validation studies.

T2P5 Validation Test Dimension List

Axilla Height
Biceps (flexed) Circumference
*Biacromial Breadth
Calf Circumference
*Chest Circumference
*Cross Shoulder
Crotch Length
Gluteal Furrow Height
Height (Stature)
High Chest Circumference (at Scye)
*Neck Circumference
*Overarm (Shoulder) Circumference
Pant Inseam (Crotch Height)
Pant Outseam (Waist Height, Preferred (side))
*Seat (Buttock) Circumference
Shoulder (Acromial) Height
*Sleeve Length (spine to wrist)
Thigh Circumference
Waist Back Length
*Waist (dress trouser) Circumference, Preferred
**Wrist (Stylion) Height

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* 1st round testing
** needed for predicting Sleeve Length; not a garment dimension

Finally, it should be noted that we used relatively inclusive criteria for dimension selection, to allow the development and testing of software well into the future. Not all the traditionally measured dimensions were tested against software extraction tools at this time.

DATA COLLECTION

Landmarking

Before being measured each subject was landmarked. These landmarks identify skeletal and other body points used to define the actual measurements. The landmarks, and their definitions are:

Acromion, right and left: The point of intersection of the lateral border of the acromial process and a line running down the middle of the shoulder from the neck to the tip of the shoulder.

Anterior scye on the torso: A short horizontal line on the torso originating at the apex of the right anterior axillary fold.

Biceps: The highest point of the right flexed biceps as viewed from the subject's right side.

Buttock: Point of maximum protrusion of the right buttock of a standing subject.

Calf: A point on the side of the calf at the level of the maximum circumference of the right calf.

Cervicale: The superior palpable point of the spine of the seventh cervical vertebra.

Deltoid (right and left): The lateral point of the right deltoid muscle, and the margin of the left deltoid muscle at the level of the right deltoid point.

Gluteal Furrow: The lowest point of the lowest furrow or crease at the juncture of the right buttock and the thigh.

Infrathyroid: The inferior point in the midsagittal plane of the thyroid cartilage (Adam's apple).

Midspine: A line down the center of the back.

Stylion: The lowest point of the bottom of the right radius.

Scye at midspine: A short horizontal line across the spine at the level of the posterior horizontal scye landmarks (a short horizontal line on the back originating at the apex of the posterior axillary fold).

Waist, preferred: The subject's preferred belt location.

For traditional measuring, small crosses or lines are drawn on the body with a marking pencil. For scanning, which requires more definition, white dots are pasted on most landmarks. In some cases, small 3-D "pegs" are affixed to the body at the landmarks to make them more visible on the scan image. In this test, the subject's belt also functioned as a landmark for waist dimension.

Traditional Measuring

After landmarking, each subject was measured for the dimensions on the **T2P5 Validation Test Dimension List** which appears on page 7. The dimensions are defined and illustrated in Appendix A. Some of the dimensions were measured twice. This was done when the scan position differed from the standardized position required by the traditional anthropometry. An example of such a dimension is overarm (shoulder) circumference. The scan pose required the arms to be held away from the torso by 20 cm at the wrist. The traditional position is with the arms hanging relaxed at the side. Moving the hands away from the thigh by 20 cm has the effect of increasing the overarm circumference. Thus measuring in both positions was necessary. The dimensions measured twice are indicated as "dowel" and "natural" in Appendix A.

After traditional data collection, the measured values were edited using ARP's data editing procedures. Very few (fewer than 10) values were identified as possibly aberrant. Those values were changed, or converted to "missing," as appropriate.

Scanning

Each test subject was scanned five times under varying conditions, as shown in Table 1. The conditions varied on landmark number and type, as well as on subject position. Multiple scans were made to enable the software team to determine which combination of position and landmarks resulted in the most complete data set for measurement extraction. Other ARN partners will report the results of that investigation.

ARN Scan versions 7.1 and 7.2 required a human operator to extract the measurement data from the scans. This work was done by one observer (Mary Gross) at ARP after all the scanning was complete. These data were not edited, since the identification of aberrant values was the point of the analysis.

TABLE 1

Scanning Conditions

SCAN	LANDMARK TYPE	LANDMARKS USED	POSE
1	None	None	Standard*
2	Flat	Anterior neck, acromion, right wrist	Standard, with dowel**
	Belt	Waist	
3	Flat	All except acromion	Standard, with dowel
	Raised	Acromion	
	Flat	Waist	
4	Flat	All except acromion	Standard, except arms relaxed at side
	Raised	Acromion	
	Belt	Waist	
5	Flat	All except acromion	Right arm forward, horizontal, elbow bent 90°, hand to the side; left arm forward, horizontal, elbow bent 90°, hand up, biceps flexed
	Raised	Acromion	
	Belt	Waist	

***Standard Pose**

Head facing forward, eyes straight ahead
Shoulders relaxed
Arms hang relaxed at sides
Palms facing the thigh
Fingers together, thumbs apart
Feet forward, 20 cm apart

**This pose varies from the standard in that arms are held out from the sides (abducted) at a distance of 20 cm, from palm to side. (The distance was established by a 20 cm dowel.)

REPEATABILITY ANALYSIS

One of the concerns with any measurement procedure is the reliability of the process. The use of human measurers in these early versions of the ARN Scan illustrated the problem. We used a repeatability analysis to assess the observer error inherent in the process. It should be noted, however, that subsequent versions of ARN Scan will incorporate automatic measurement procedures so this issue will disappear.

Three operators (measurers) extracted measurements from each of ten male subjects three times (sessions). We reduced any learning effect by allowing the measurers to practice on ten male subjects who were not part of the experimental sample. We randomized the subject order in three blocks and standardized rules for locating landmarks among the three measurers. All measurers had some previous experience with landmarking on humans. Table 2 contains a list of the landmarks required by the measurement algorithms, the method of landmark location (automatic or manual), the measurements using the landmark, and the measurement algorithm developer.

TABLE 2

Landmarks, Method, Developer

Landmark	**Location**	**Measurement (Developer**) Method**
Acromion, Right	Automated*	Cross Shoulder (Cyber)
		Sleeve Lth (Cyber)
		Sleeve Lth (BRC)
Acromion, Left	Automated	Cross Shoulder (Cyber)
		Sleeve Lth (Cyber)
		Sleeve Lth (BRC)
Bustpoint, Left	Manual	Chest Circ (Cyber)
		Chest Circ (BRC)
Chest at Scye, Right	Manual	Chest Circ (BRC)
Crotch Level	Manual	Seat Circ (BRC)
		Inseam Lth (Cyber)
Elbow, Right	Manual	Sleeve Lth (Cyber)
Suprasternale	Automated*	Neck Circ (BRC)
		Sleeve Lth (Cyber)
		Sleeve Lth (BRC)
Waist, Right	Automated*	Waist Circ (BRC)
		Waist Circ (Cyber)
Wrist, Right	Manual	Sleeve Lth (BRC)
		Sleeve Lth (Cyber)

*The algorithm to locate this landmark automatically frequently does not work. Measurers must then manually select the location.

** BRC = Beecher Research Company; Cyber = Cyberware Laboratory, Inc.

We conducted a full-factorial repeated measures analysis on the marginal means of the within–subject factors, operator, and session. (Conducting the analysis using each individual observation resulted in insufficient degrees of freedom for multivariate test statistics.) The dependent variables include crotch height, neck circumference, overarm circumference, sleeve length (BRC), sleeve length (Cyber), chest circumference (BRC), chest circumference (Cyber), waist circumference (BRC), waist circumference (Cyber), seat circumference, and cross shoulder distance (biacromial breadth).

One of the assumptions associated with repeated measures analysis is that the measurements on a subject should be from a multivariate normal distribution. This is a fair assumption for these data. Another assumption is that the variance-covariance matrices of the dependent variables are equal for each operator by session combination. This is commonly referred to as the sphericity assumption. There is a statistical test for sphericity (Mauchly's), but it is not very powerful for small samples. Therefore, we assumed that these data violate the sphericity assumption and applied the Huynh-Feldt correction to the numerator and denominator degrees of freedom for testing.

Multivariately, there is strong evidence that the vectors of mean values between measurers are significantly different (Wilks' Lambda p=.011, Pillai's Trace p=.030). An estimated 74.8% (Pillai's Trace Eta ^{2}) to 81.3% (Wilks' Lambda Eta ^{2}) of the variation in all the measurements is due to measurer. This seems high, but univariate tests (described below) indicate that this error is concentrated among a few measurements. There is some weak evidence that the interaction between measurer and session is significant (Wilks' Lambda p=.048, Pillai's Trace p=. 169). This means that the operators' mean vectors are not the same for all sessions.

Univariate tests indicate that significant differences between operators occur in inseam (p=.000) , sleeve length (Cyber) (p=.036), and cross shoulder (p=.032). Overarm circumference is nearly significant at p=.056. None of the measurements are significant for the operator–by–session interaction. Quite possibly, the multivariate interaction is truly insignificant. We will make this assumption.

Table 3 contains some summary statistics for measurer error.

TABLE 3

Summary Statistics for Absolute Value of Differences Between Measurers
(values in mm)

MEASUREMENT	MIN	MAX	MEAN	STD DEV	% ± 12 mm
Pant Inseam Lth	0.00	28.00	12.67	9.07	53.3
Neck Circ	0.00	30.00	2.60	7.03	93.3
Overarm Circ	0.00	42.00	8.07	8.64	86.7
Sleeve (BRC)	1.00	37.00	8.60	8.98	66.7
Sleeve (Cyber)	0.00	66.00	28.87	20.66	30.0
Chest (BRC)	0.00	41.00	8.67	11.34	70.0
Chest (Cyber)	0.00	17.00	5.60	4.59	90.0
Waist (BRC)	0.00	27.00	2.20	6.28	93.3
Waist (Cyber)	0.00	44.00	3.53	10.22	93.3
Hip Circ	0.00	22.00	4.80	6.71	83.3
Cross Shoulder	0.00	21.00	8.07	6.27	86.7

The largest mean error is in Sleeve (Cyber). Since the Sleeve (BRC) is much more accurate, that algorithm will be used. The large error detected in pant inseam is probably due to differences in the location on the body used for selecting the crotch landmark. Two measurers selected crotch on the thigh, while the third selected crotch directly at the crotch. We had instructed the measurers that it did not matter where crotch was picked, because we were only interested in the crotch level. This was what the software developers had indicated. Clearly, these results show that it *does* matter.

Measurer error is certainly within acceptable limits for some measurements. Measurement error appears to be mainly a result of differences in measurement position and problems with landmark location (acromion, in particular). Both of these issues were being addressed in the San Diego field test. Measurement positions have been standardized between measurement methods, and the software release in production provides automatic landmark detection. However, some differences are clearly large enough to result in the assignment of an incorrect size.

Note that this is primarily a test of manual landmarking. It indicates that operator intervention should be minimized. However, when landmark identification is fully automated, it needs to be tested again. Then, the test will have two components: 1) testing the repeatability of the software routines, and 2) testing whether the software can correctly identify the same point as identified by the expert anthropometrist on the live human subject.

DATA ANALYSIS

The main focus of the data analysis is to compare the body measurements obtained by ARN Scan versions 7.0 and 7.1 to those obtained by using traditional methods. First, however, we are concerned with determining what kind of sample we achieved during data collection.

We compared the validation sample to ANSUR to determine whether it represented the range of body size and shape one might encounter in a military population. Figures 1 through 4 indicate that the distributions for this sample and the ANSUR sample overlap nicely for Stature with Chest Circumference (Figures 3 and 4 for males and females) and Stature and Seat (Buttock) Circumference (Figures 5 and 6 for males and females).

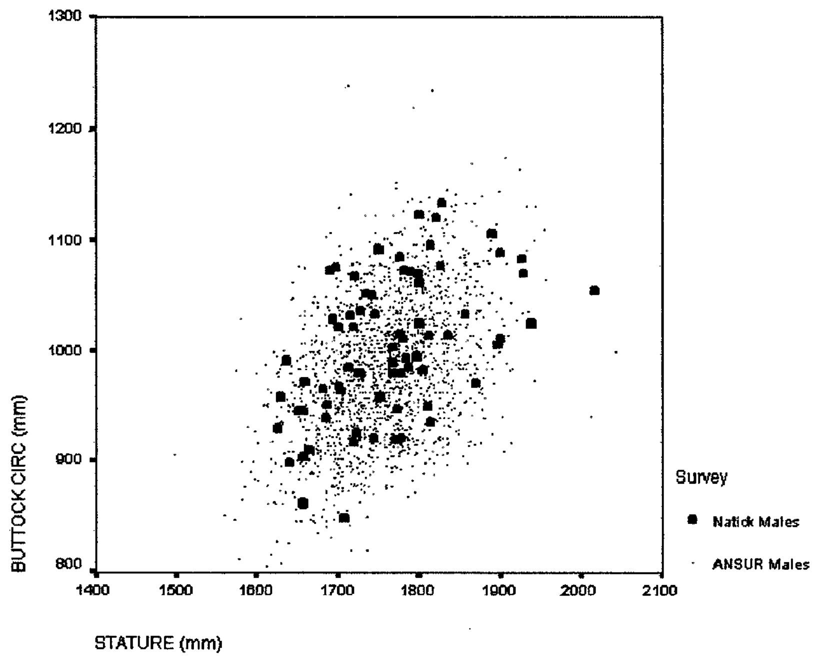

FIGURE 3

Natick Validation Males on ANSUR Distribution
of Stature and Chest Circumference

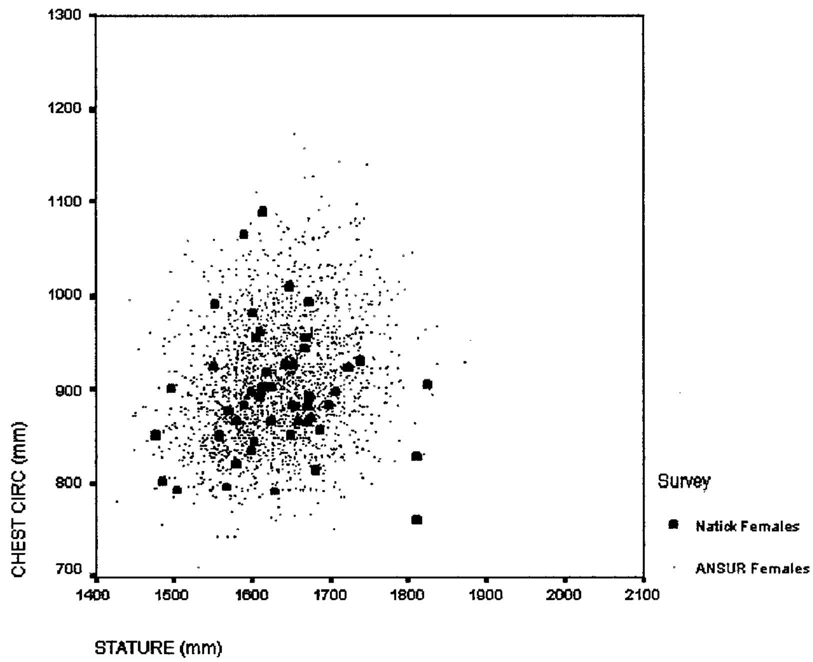

FIGURE 4

Natick Validation Females on ANSUR Distribution
of Stature and Chest Circumference

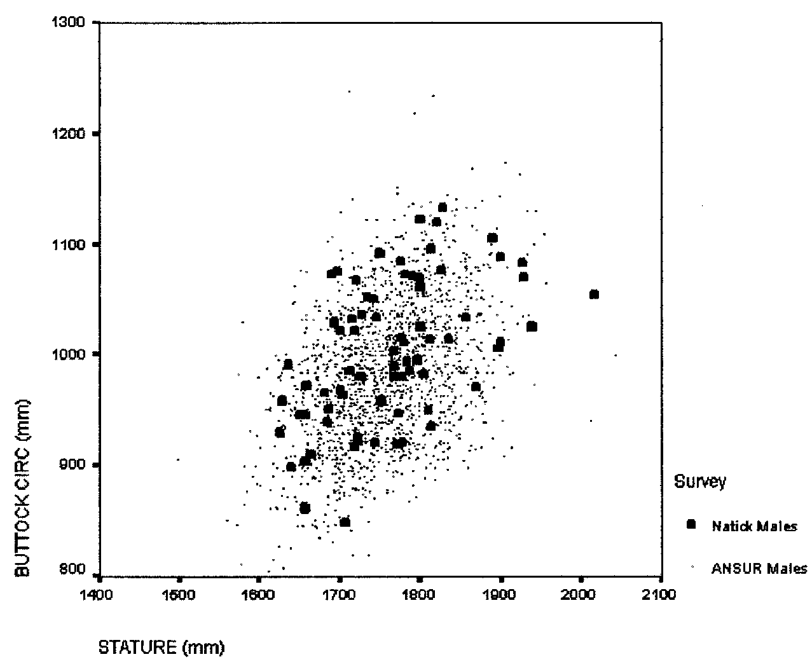

FIGURE 5

Natick Validation Males on ANSUR Distribution
of Stature and Buttock Circumference

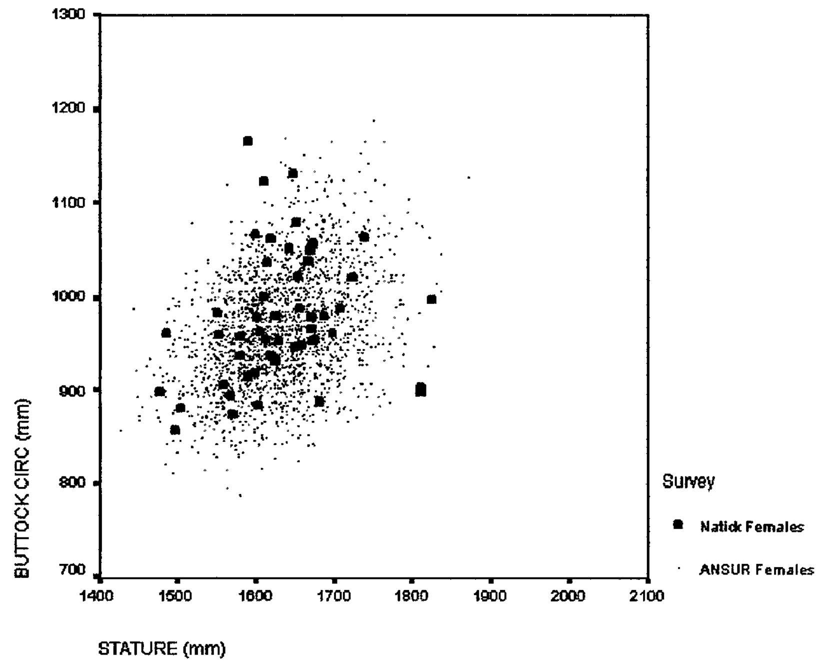

FIGURE 6

Natick Validation Females on ANSUR Distribution
of Stature and Buttock Circumference

Summary statistics and percentile tables for the traditional anthropometry are provided in Tables 4 and 5.

The way we compare the two measurement methods, traditional and ARN Scan, is to subtract the value obtained by one method from the value obtained by the other. If the two methods were equivalent, the subtracted differences would be zero. Table 6 contains the formulas used to compute the differences between the traditional and ARN Scan measurements. For some measures, ARN Scan provides two–measurement computational methods to compare. These are referred to as B1 and B2.

TABLE 4

Male Descriptive Statistics: Natick Validation Sample
(values in mm)

DIMENSION	N	MIN	MAX	MEAN	STD DEV
Axilla (Armpit) Height	73	1214.00	1522.00	1332.3836	70.3631
Biacromial Breadth	73	346.00	452.00	399.8493	20.9720
Biceps (Flexed) Circumference	73	251.00	423.00	335.6849	32.8802
Calf Circumference	73	320.00	454.00	382.0548	27.5121
Chest (Bust) Circumference	73	843.00	1177.00	1005.7808	82.3268
Crotch Length	73	636.00	839.00	728.8219	42.1526
Cross Shoulder	73	375.00	501.00	445.7534	28.4096
Gluteal Furrow Height	73	718.00	927.00	805.0822	52.1892
Height (Stature)	73	1625.00	2017.00	1763.5342	81.9365
High Chest Circ (at Scye)	73	858.00	1202.00	1024.6027	75.8899
Neck Circumference	73	328.00	451.00	385.0685	27.8340
Overarm (Shoulder) Circ, Dowel	73	1038.00	1345.00	1200.1370	78.9244
Overarm (Shoulder) Circ, Natural	73	1009.00	1375.00	1185.8356	80.4517
Pant Inseam (Crotch Height)	73	677.00	907.00	769.9315	54.2211
Pant Outseam (Waist Height, Pref)	52	972.00	1222.00	1061.4038	63.9446
Seat (Buttock) Circ	73	849.00	1133.00	1003.4247	64.3907
Shoulder (Acromial) Height	73	1319.00	1651.00	1446.4658	75.7623
Sleeve Length (Spine to Wrist)	73	755.00	991.00	876.9589	50.7930
Thigh Circumference	73	465.00	691.00	597.6438	46.8139
Waist Back Length	73	389.00	552.00	466.8767	31.6245
Waist (Dress Trouser) Circ, Pref	73	701.00	1049.00	893.9589	84.5121
Waist Height	73	961.00	1216.00	1059.0137	61.0049
Wrist (Stylion) Height, Dowel	73	818.00	1055.00	935.8219	51.0926
Wrist (Stylion) Height, Natural	73	619.00	977.00	858.7808	62.4474

TABLE 5

Female Descriptive Statistics: Natick Validation Sample
(values in mm)

DIMENSION	N	MIN	MAX	MEAN	STD DEV
Axilla (Armpit) Height	50	1100.00	1337.00	1228.4400	48.1698
Biacromial Breadth	50	320.00	389.00	355.9000	18.6156
Biceps (Flexed) Circumference	50	238.00	333.00	280.0400	25.0990
Calf Circumference	50	292.00	430.00	352.6000	26.5168
Chest (Bust) Circumference	50	762.00	1090.00	895.2400	66.7275
Crotch Length	50	657.00	859.00	733.9200	45.1437
Cross Shoulder	50	339.00	452.00	392.6600	25.1888
Gluteal Furrow Height	50	653.00	853.00	728.1800	38.6458
Height (Stature)	50	1477.00	1823.00	1632.0000	74.2843
High Chest Circ (at Scye)	50	771.00	1098.00	882.1000	61.7220
Neck Circumference	50	279.00	384.00	317.7600	18.9053
Overarm (Shoulder) Circ, Dowel	50	931.00	1271.00	1049.4400	62.8335
Overarm (Shoulder) Circ, Natural	50	919.00	1254.00	1032.9400	64.6654
Pant Inseam (Crotch Height)	50	625.00	794.00	721.2400	38.7528
Pant Inseam (Crotch Height)	50	625.00	794.00	721.2400	38.7528
Seat (Buttock) Circ	50	858.00	1168.00	977.6600	70.4147
Shoulder (Acromial) Height	50	1189.00	1431.00	1324.1800	48.9784
Sleeve Length (Spine to Wrist)	50	714.00	848.00	779.4400	33.2702
Thigh Circumference	50	478.00	698.00	580.9800	51.7279
Waist Back Length	50	329.00	458.00	384.2800	24.3713
Waist (Dress Trouser) Circ, Pref	50	621.00	990.00	736.3000	74.8916
Waist Height	50	847.00	1112.00	1012.7000	51.0107
Wrist (Stylion) Height, Dowel	50	830.00	961.00	890.7400	35.3327
Wrist (Stylion) Height, Natural	50	733.00	872.00	804.5800	34.2673

TABLE 6

Formulas for Calculating Measurement Differences

Measurement Difference	**=**	**Traditional Measurement**	**–**	**ARN Scan Measurement**
Biacromial Brdth Difference	=	Biacromial Brdth	–	Cross Shoulder
Chest Circ 1 Difference	=	Chest (Bust) Circ	–	Chest Circ
Chest Circ 2 Difference	=	Chest (Bust) Circ	–	Chest Circ
Crotch Ht Difference	=	Pant Inseam (Crotch Ht)	–	Inseam
Hip Circ Difference	=	Seat (Buttock) Circ	–	Seat Circ
Neck Circ Difference	=	Neck Circ	–	Neck Collar
Shoulder Circ Difference	=	Overarm (Shoulder Circ), Dowel	–	Overarm
Sleeve Lth 1 Difference	=	Sleeve Lth (Spine to Wrist)	–	Sleeve Lth
Sleeve Lth 2 Difference	=	Sleeve Lth (Spine to Wrist)	–	Sleeve Lth
Waist Circ 1 Difference	=	Waist (Dress Trouser) Circ, Pref	–	Waist Circ
Waist Circ 2 Difference	=	Waist (Dress Trouser) Circ, Pref	–	Waist Circ

One of the challenges of this kind of effort is determining the test standard against which the results will be measured. There are a number of criteria that might be applied. One might be published targets, such as the Technical Error of Measurement (Cameron, 1984) but those often refer to laboratory exercises, rather than to actual data collection conditions. A standard that might be more useful here is actual observer error from a large data collection effort under realistic conditions. ANSUR was a large survey in which observer error data were collected for a subset of the total sample. It has the advantage of using the same measuring techniques as were used in this validation study. Another standard we might apply to these data is something from the field of apparel design and sizing where, after all, final ARN Scan software will be applied. We asked 3 ARN partners with expertise in garment design and issuing to assess what level of measurement error would be acceptable in their work. They provided us with acceptable error levels for most of the critical dimensions we tested. Finally, the garment grade itself might be used. What magnitude of measurement difference would move the person to the next size. We believe that a combination of these benchmarks – ANSUR observer error and garment-specific error values – will provide the best assessment of the results of this validation test.

The statistic we chose to report the measurement differences is the Mean Absolute Difference (M.A.D.). This is calculated by taking the absolute value of each of the individual differences, and then taking the mean of those absolute value differences. This is a statistic that measures how far apart the two techniques are. Absolute values are used because the use of directional values could have a misleading effect and lead to false conclusions. For instance, if 20 subjects had a difference of –1 and another 20 subjects a difference of +1, the mean would be 0. Relying on the mean alone, we would conclude that there is no difference between the traditional and ARN Scan measurements. In addition, directional differences are not of concern here. We do not care if the ARN Scan measurement is 1" less or 1" more than the traditional measurement; we only care that it is 1" different.

Tables 7 and 8 contain the validation and ANSUR M.A.D. values, as well as the validation minimum and maximum values.

TABLE 7

ARN Validation Males
Descriptive Statistics for Absolute Value of Difference
(values in inches)

	ARN ABSOLUTE DIFFERENCES					ANSUR ABSOLUTE DIFFERENCES
DIMENSION	N	MIN	MAX	STD DEV	MEAN	
Cross Shoulder	70	0.00	1.85	0.47	0.52	0.14
Chest Circ 1	60	0.00	3.23	0.81	1.04	0.27
Chest Circ 2	70	0.00	2.72	0.64	0.77	0.27
Crotch Height	70	0.00	1.34	0.33	0.41	0.24
Seat Circumference	70	0.00	3.50	0.47	0.44	0.16
Neck Collar Circ	67	0.00	3.54	0.49	0.40	0.14
Overarm Circ	70	0.00	10.94	1.71	1.74	0.23
Sleeve Length 1	70	0.00	9.45	1.19	0.83	0.20
Sleeve Length 2	37	0.12	7.36	1.35	2.30	0.20
Waist Circ 1	70	0.00	3.23	0.53	0.51	0.19
Waist Circ 2	65	0.00	3.66	0.71	0.96	0.19

TABLE 8

ARN Validation Females
Descriptive Statistics for Absolute Value of Difference
(values in inches)

	ARN ABSOLTUE DIFFERENCES					ANSUR ABSOLUTE DIFFERENCES
	N	MIN	MAX	MEAN	STD DEV	
Cross Shoulder	49	0.08	1.57	0.61	0.41	0.14
Chest Circ 1	23	0.04	2.64	0.63	0.69	0.24
Chest Circ 2	49	0.04	3.15	0.65	0.62	0.24
Crotch Height	49	0.00	1.65	0.63	0.38	0.14
Seat Circumference	49	0.00	1.06	0.31	0.26	0.17
Neck Collar Circ	47	0.00	0.83	0.28	0.22	0.12
Overarm Circ	49	0.00	5.24	1.68	1.18	0.20
Sleeve Length 1	49	0.00	2.05	0.64	0.52	0.20
Sleeve Length 2	21	0.67	3.62	2.26	0.85	0.20
Waist Circ 1	49	0.00	1.65	0.48	0.44	0.18
Waist Circ 2	49	0.16	2.80	0.81	0.53	0.18

The tables illustrate a number of points. First, all the M.A.D.s are larger than the ANSUR observer error. Some—for example overarm and sleeve length 2—are dramatically larger. Crotch height and neck are the best, for males, and hip and neck are the best for females. Nevertheless, the ANSUR observer error is not the only useful criterion available as a test measure.

Table 9 shows the validation study M.A.D. compared to the tailor estimates of acceptable difference for those dimensions where we have tailor estimates. For male test subjects, the M.A.D.s are larger than the tailor estimates for all measurements except crotch and seat, where the differences are greater than would have been allowed by Tailors 1 and 2, but are within that allowed by Tailor 3. For females, the ARN Scan Traditional differences are greater than would be allowed by all the tailors on all dimensions except neck (within rounding), seat, and waist 1. For waist 1, the M.A.D. is outside what would be allowed by Tailor 1, but within the range for Tailors 2 and 3.

TABLE 9

Validation M.A.D. Compared to Tailor Estimates
(values in inches)

	MALE M.A.D.	FEMALE M.A.D.	TAILOR		
			1	2	3
Chest Circ	.770	.648	±.375	-.25 to +.5	±.5
Pant Inseam	.414	.633	±.375	-.25 to +.5	±.5
Neck	.398	.278	±.25	±.25	±.25
Seat Circ	.445	.306	±.375	-.25 to +.5	±.5
Sleeve Length 1	.828	.637	±.25	-.25 to +.5	±.5
Sleeve Length 2	2.297	2.265	±.25	-.25 to +.5	±.5
Waist Circ 1 (NI)	.510	.479	±.375	-.25 to +.5	±.5
Waist Circ 2 (NI)	.959	.811	±.375	-.25 to +.5	±.5

The garment grade is a more forgiving criterion. Table 10 shows the M.A.D for males and females displayed with the garment grade for military dress clothing. Here, the ARN Scan Traditional difference is less than the garment grade on all dimensions. Thus, a difference of the size indicated would have placed an individual in the correct size anyway. It should be emphasized, however, that the M.A.D. refers to the *mean* value and that individual values are greater than this. Therefore, even with this relatively relaxed criterion, some individuals would find the wrong garment using the ARN Scan measurement.

TABLE 10

Mean Absolute Difference and Garment Grade
(values in inches)

	MALE M.A.D.	FEMALE M.A.D.	GARMENT GRADE
Chest Circ	.770	.648	1
Pant Inseam	.414	.633	2
Neck Circ	.398	.278	.5
Seat Circ	.445	.306	1
Sleeve Length 1	.828	.637	1
Sleeve Length 2	2.297	2.265	1
Waist Circ 1 (NI)	.510	.479	1
Waist Circ 2 (NI)	.959	.811	1

Table 11 summarizes the results from all three criteria: ANSUR observer error, tailors' estimates of acceptable error, and garment grade. In the table, X indicates that the measure fails the criterion. O indicates it passes the criterion. Blank indicates that the criterion is not defined for that measure.

TABLE 11

ARN Validation Data: Summary of Statistical Results

	MALES			FEMALES		
DIMENSIONS	ANSUR	Tailor	Grade	ANSUR	Tailor	Grade
Cross Shoulder Difference	X		O	X		O
Chest Circ 1 Difference	X	X	O	X	X	O
Chest Circ 2 Difference	X	X	O	X	X	O
Pant InseamDifference	X	O	O	X	X	O
Seat Circ Difference	X	O	O	X	O	O
Neck Circ Difference	X	X	O	X	O	O
Shoulder Circ Difference	X		O	X		O
Sleeve Lth 1 Difference	X	X	O	X	X	O
Sleeve Lth 2 Difference	X	X	X	X	X	X
Waist Circ 1 Difference	X	X	O	X	O	O
Waist Circ 2 Difference	X	X	O	X	X	O

CONCLUSION

This project provided one evaluation of ARN Scan versions 7.1 and 7.2, available for use in February and March, 1998. The evaluation focused on comparing measurements extracted from ARN Scan with measurements of the same subjects obtained in the traditional way. While there were certainly similarities in the way the two techniques measured, there were many instances in which the ARN Scan value was different from the traditionally measured value. We used several criteria to determine whether these differences were important or significant. These were: (1) comparison to a large traditionally measured data base, where human measuring error was well documented, (2) estimates by three experienced tailors of acceptable levels of measurement error, and (3) the garment grade in traditionally sized dress clothing. For the most part, the ARN Scan method fared well against the garment grade criterion. It did not fare well against the acceptable observer error standards established in the ANSUR Survey. Comparing the differences to the estimates of experienced tailors provided a mixed result, where some dimensions met the evaluation criteria, and others did not.

ARN Scan is a software product undergoing continuing improvement. At this writing, some of the dimensions identified as problems here are likely to have been improved to the point that they meet the tailors' criteria, if not the ANSUR error criteria. Further, more substantial testing, with a larger sample size, were carried out in the Spring of 1998. Those results should be available in late 1998.

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Clauser, Charles, Ilse Tebbetts, Bruce Bradtmiller, John McConville and Claire Gordon, 1988, *Measurer's Handbook: U.S. Army Anthropometric Survey, 1987-1988*, Technical Report NATICK/TR-88-043 (AD A164 637), U.S. Army Natick Research, Development and Engineering Center, Natick, Massachusetts.

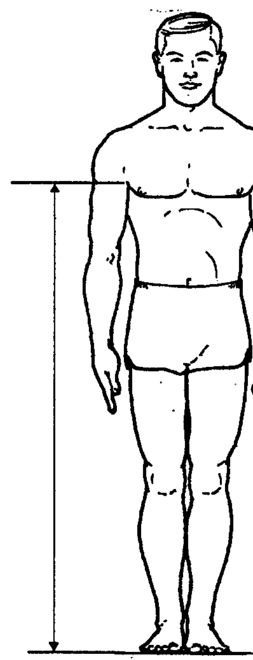
Gordon, Claire C., Bruce Bradtmiller, Charles E. Clauser, Thomas Churchill, John T. McConville, Ilse Tebbetts and Robert A. Walker, 1989, *1987-1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*, Technical Report NATICK/TR-89-044, U.S. Army Natick Research, Development and Engineering Center, Natick, Massachusetts.

APPENDIX

DIMENSION DESCRIPTIONS

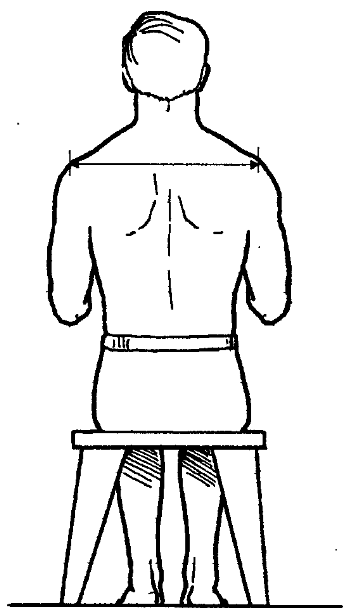
AXILLA (ARMPIT) HEIGHT

The vertical distance between a standing surface and the right axillary fold, as designated by the anterior-scye-on-the-torso landmark, is measured with an anthropometer. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed with the palms facing the thighs. The measurement is taken at the maximum point of quiet respiration.



BIACROMIAL BREADTH

The distance between the right and left acromion landmarks at the tips of the shoulders is measured with a beam caliper. The subject sits erect. The shoulders and upper arms are relaxed and the forearms and hands are extended forward horizontally with the palms facing each other. The measurement is taken at the maximum point of quiet respiration.

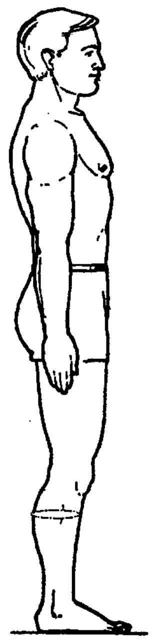


BICEPS (FLEXED) CIRCUMFERENCE

The circumference of the right upper arm around the flexed biceps muscle is measured with a tape held perpendicular to the long axis of the upper arm. The subject stands with the upper arm extended horizontally and the elbow flexed 90 degrees. The fist is clenched and held facing the head, and the subject exerts maximum effort in "making a muscle."

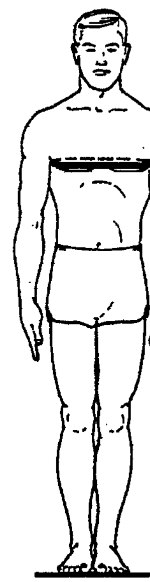
CALF CIRCUMFERENCE

The maximum horizontal circumference of the right calf is measured with a tape. The subject stands erect with the heels approximately 10 cm apart and the weight distributed equally on both feet.



CHEST (BUST) CIRCUMFERENCE

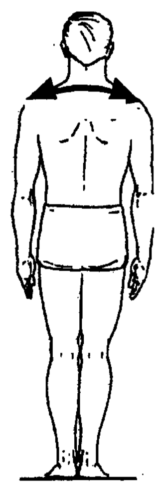
The maximum horizontal circumference of the chest at the fullest part of the breast is measured with a tape. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.



CROSS SHOULDER

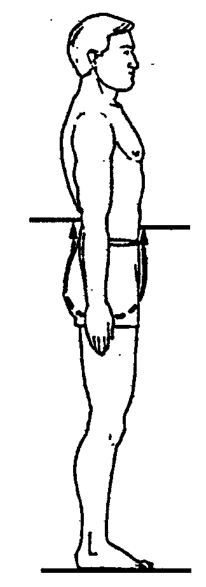
Subject is in the anthropometric standing position. Stand behind the subject and use a tape to measure the distance between the drawn acromion landmarks. The tape is held flat on the skin where it arches up over the shoulder blades. The measurement is taken at the maximum point of quiet respiration.

Caution: The subject must not be allowed to change the position of the shoulders.



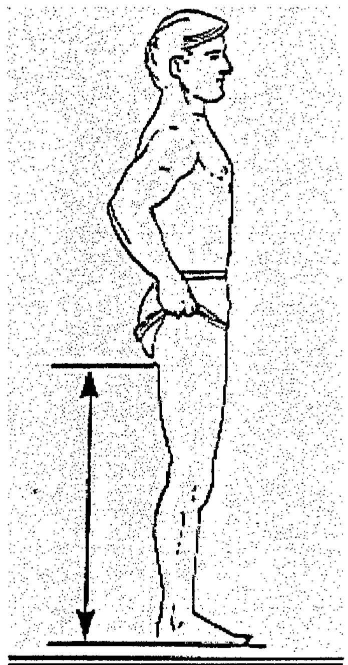
CROTCH LENGTH

The distance between the abdomen at the level of the preferred landmark of the waist to the preferred landmark on the back is measured with a tape passing through the crotch to the right of the genitalia. The tape is held vertically both in front and in back. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The measurement is taken at the maximum point of quiet respiration.



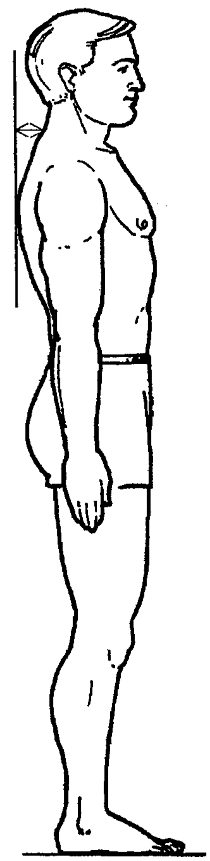
GLUTEAL FURROW HEIGHT

The vertical distance between a standing surface and the lowest point of the gluteal furrow(s) under the right buttock is measured with an anthropometer. The subject stands erect with the heels together and the weight distributed equally on both feet.



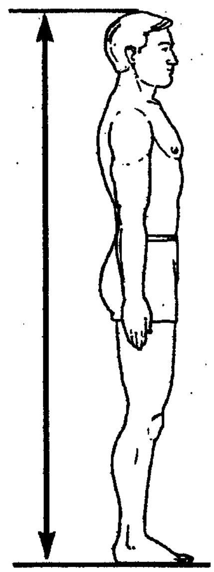
HEAD A TO X

The horizontal distance of the neck from the plane of the two scapulae (shoulder blades) is measured with a Head A to X measuring tool (available from Phil Perkins Tailoring Instruments). The subject stands erect with the heels together and the weight equally distributed on both feet. The head is in the Frankfort plane.



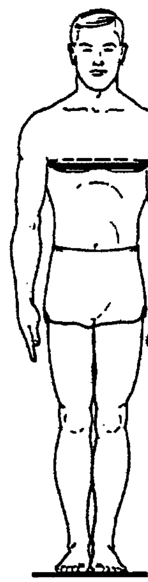
HEIGHT (STATURE)

The vertical distance from a standing surface to the top of the head is measured with an anthropometer. The subject stands erect with the head in the Frankfort plane. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.



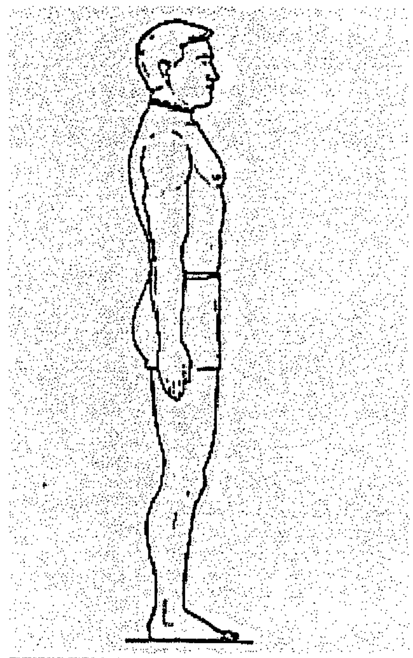
HIGH CHEST CIRCUMFERENCE (AT SCYE)

The horizontal circumference of the chest at the level of the scye-at-midspine landmark is measured with a tape. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.



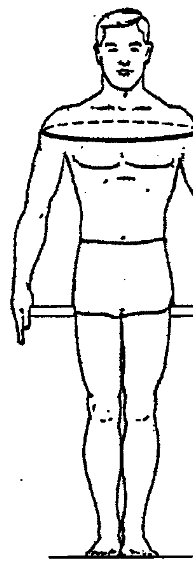
NECK CIRCUMFERENCE

The circumference of the neck at the level of the infrathyroid landmark (Adam's apple) is measured with a tape. The plane of the measurement is perpendicular to the long axis of the neck. The subject stands erect with the head in the Frankfort plane. The shoulders and upper extremities are relaxed.



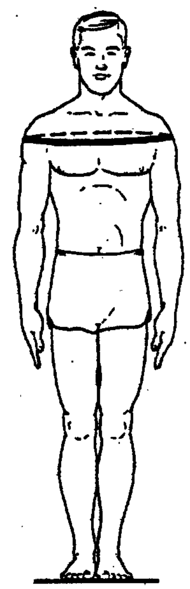
OVERARM (SHOULDER) CIRCUMFERENCE, DOWEL

The horizontal circumference of the shoulders at the level of the maximum protrusion of the right deltoid muscle as the arms are supported outward by a dowel held in each hand against the thigh area is measured with a tape. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed with the palms facing the thighs. The measurement is taken at the maximum point of quiet respiration.



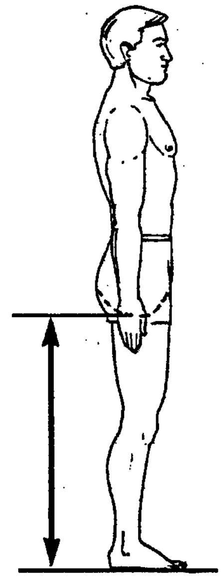
OVERARM (SHOULDER) CIRCUMFERENCE, NATURAL

The horizontal circumference of the shoulders at the level of the maximum protrusion of the right deltoid muscle is measured with a tape. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed with the palms facing the thighs. The measurement is taken at the maximum point of quiet respiration.



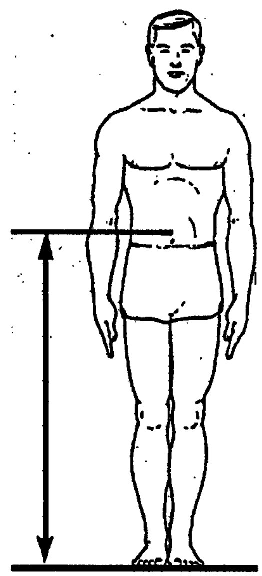
PANT INSEAM (CROTCH HEIGHT)

The vertical distance between the standing surface and the crotch is measured with an anthropometer. The subject stands erect looking straight ahead. The heels are together and the weight is distributed equally on both feet.



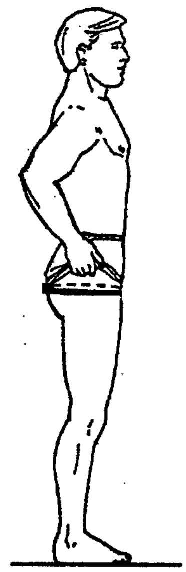
PANT OUTSEAM (WAIST HEIGHT, PREFERRED (side))

The vertical distance between a standing surface and the landmark at the preferred landmark of the right waist is measured with an anthropometer. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.



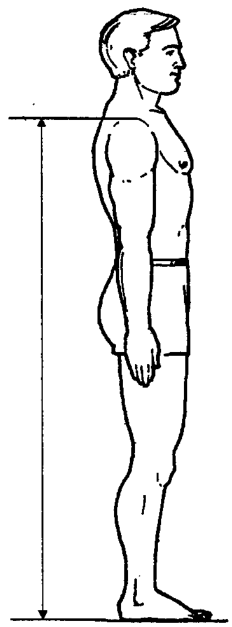
SEAT (BUTTOCK) CIRCUMFERENCE

The horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock is measured with a tape. The subject stands erect with the heels together and the weight equally distributed on both feet.



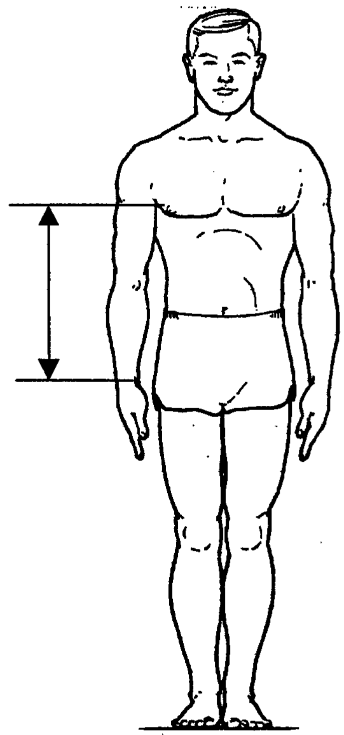
SHOULDER (ACROMIAL) HEIGHT

The vertical distance between a standing surface and the acromion landmark on the tip of the right shoulder is measured with an anthropometer. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.



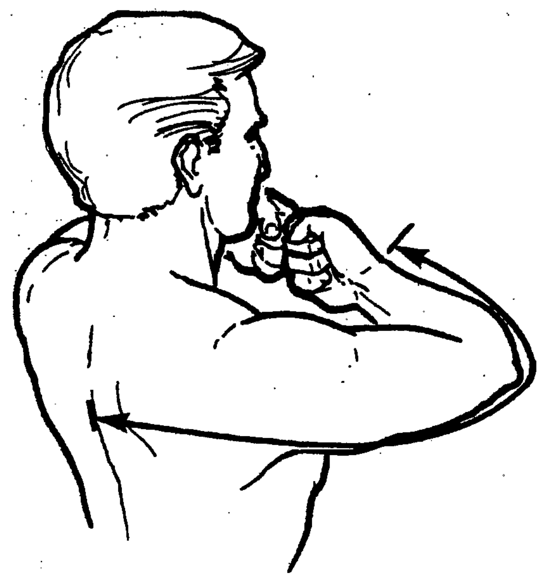
SLEEVE INSEAM

Calcualted as Axilla (Armpit) Height minus Wrist (Stylion) Height, Natural).



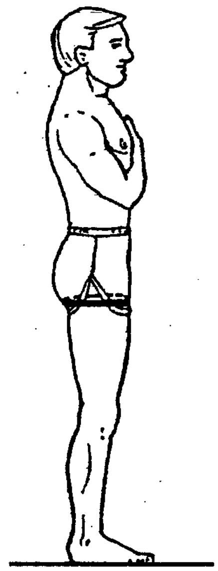
SLEEVE LENGTH (SPINE TO WRIST)

The horizontal surface distance from the midspine landmark, across the olecranon-center landmark at the tip of the raised right elbow, to the dorsal wrist landmark is measured with a tape. The measurement is made while the subject holds his/her arms up in a horizontal position parallel to the standing surface and joins them by bringing the fists together at the metacarpophalangeal and proximal interphalangeal knuckles. The forearms and fists are in a straight line.



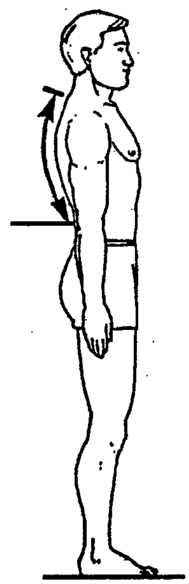
THIGH CIRCUMFERENCE

The circumference of the right thigh at its juncture with the buttock is measured with a tape. The measurement is made perpendicular to the long axis of the thigh. The subject stands erect with the weight distributed equally on both feet. The legs are spread apart just enough so that the thighs do not touch.



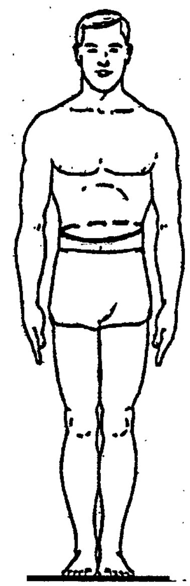
WAIST BACK LENGTH

The surface distance between the cervicale landmark at the back of the neck and the posterior-waist (preferred) landmark is measured with a tape. The subject stands erect with the head in the Frankfort plane. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.



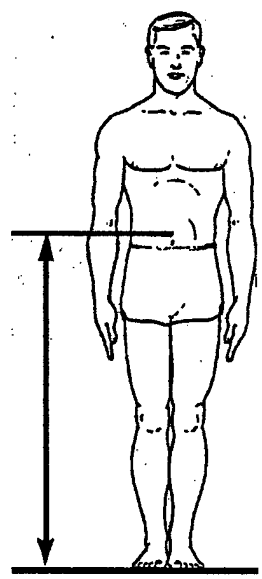
WAIST (DRESS TROUSER) CIRCUMFERENCE (PREFERRED)

The horizontal circumference of the waist at the level of the preferred landmark is measured with a tape passing over the right and left waist (preferred) landmarks. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The measurement is made at the maximum point of quiet respiration.



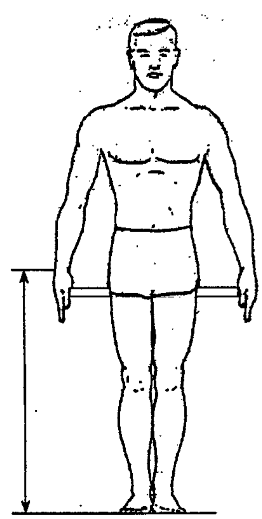
WAIST HEIGHT

The vertical distance between a standing surface and the preferred landmark at the right waist is measured with an anthropometer. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.



WRIST (STYLION) HEIGHT, DOWEL

The vertical distance between a standing surface and the stylion landmark on the right wrist while the hand is grasping a dowel which is supported by the thigh is measured with an anthropometer. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet. The shoulders are relaxed and the arms are extended downwards with the elbow, wrist, and fingers held rigidly straight. The arms lightly touch the sides. The measurement is taken at the maximum point of quiet respiration.



WRIST (STYLION) HEIGHT, NATURAL

The vertical distance between a standing surface and the stylion landmark on the right wrist is measured with an anthropometer. The subject stands erect looking straight ahead with the heels together and the weight distributed equally on both feet. The shoulders are relaxed and the arms are extended downwards with the elbow, wrist, and fingers held rigidly straight. The arms lightly touch the sides. The measurement is taken at the maximum point of quiet respiration.