REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	27 May 97	Final Report 01 Mar 98 - 31 Dec 98

4. TITLE AND SUBTITLE
Standardized Measurement Procedures Phase II: Validation of Measurements- Marine Corps Test (MPG1-P1, Phase 2)

5. FUNDING NUMBERS

6. AUTHOR(S)
BRUCE BRADTMILLER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Anthropology Research Project, Inc.
503 Xenia Avenue
Yellow Springs, OH 45387

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Defense Logistics Agency
MMPRT Room 3135
8725 John J. Kingman Road, #2533
Fort Belvoir, VA 22060-6221

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

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

This project had three primary goals: to examine the relationship between human body measurements taken with measuring tapes and those extracted from whole body scans with ARNScan software; to examine an approach to garment size selection based on multivariate analysis of dimensions extracted from whole body scans; and to examine anthropometric changes in Marine Corps recruits during the course of basic training.

We used recruits processed at the Marine Corps Recruit Depot – San Diego as test subjects. The recruits were scanned by a Cyberware WB4 whole body scanner, and measurements were extracted using ARNScan software.

We compared a series of software-extracted measurements to traditional measurements taken with a tape. The mean differences, those averaged over all individuals, ranged from 6 mm (.25 inch) on neck circumference to 66 mm (2.6 inches) on sleeve length.

Finally, we examined anthropometric changes which occur in association with Marine Corps basic training. Many recruits lost weight, but the biggest changes were reductions in a number of torso circumferences, indicating a loss of body fat, and relative increase in muscle. Over 95% of recruits experienced some change in body dimensions, and many of these changes were larger than the garment grade in dress clothing.

14. SUBJECT TERMS:	15. NUMBER OF PAGES
anthropometry, 3D, whole body scans, ARNScan, clothing, Weight change	56
	16.

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

DLA-ARN Short-Term Project Report

Defense Logistics Agency: Apparel Research Network

STANDARDIZED MEASUREMENT PROCEDURES PHASE II: VALIDATION OF MEASUREMENTS – MARINE CORPS TEST (MPG1 T1- P1, Phase 2)

Anthropology Research Project, Inc.

Contract Number	SPO100-95-D-1010
Contractor	Anthropology Research Project, Inc.
Delivery Order #	0005
Delivery Order Title	Standardized Measurement Procedures-Ph. 2 - Marine Corps Test
CDRL #	A002 (Unclassified)
CDRL Title	Interim Progress and Technical Report
Reporting Period	1 March 1998 - 31 December 1998
Report Date	18 June, 1999
Name of PI	Dr. Bruce Bradtmiller
E-mail	bruce@anthrotech.net
Phone	937-767-7226
Fax	937-767-9350
Address	Box 307, Yellow Springs, OH 45387

EXECUTIVE SUMMARY

In the first phase of this effort, reported as *Reconciling Anthropometric and Tailoring Measurements for Clothing Design*, (T1P1 Phase 1, May, 1997), we examined the differences between the way tailors take measurements, and the way anthropologists take the same measurements. The focus of that study was to bridge the significant gap between methods, so that the special measurement expert systems and electronic order forms would be able to make use of the large military anthropometric data bases which have been created by anthropologists.

This report, on the activities of T1P1 Phase 2, bridges traditional measurement methods and newer methods. In it we describe efforts to tie the measurements extracted from the scan images to measurement taken from the same individuals using tape measures and other traditional tools. Since the extracted measurements will ultimately be used in clothing design or selection, it is critically important to understand how the extracted measurements are the same as, or are different from, the traditional measures used by the clothing industry.

This project had three primary goals: to examine the relationship between human body measurements taken with traditional tools (tapes, etc.) and those extracted from whole body scans with ARNScan software; to examine an approach to garment size selection based on multivariate analysis of dimensions extracted from whole body scans; and to examine anthropometric changes in Marine Corps recruits during the course of basic training.

We used recruits processed at the Marine Corps Recruit Depot – San Diego as test subjects. The recruits were scanned by a Cyberware WB4 whole body scanner, and measurements were extracted using ARNScan software. ARNScan is a developmental software product funded in part by the Defense Logistics Agency, under its Apparel Research Network. In addition, we measured the same recruits using tape measures and other traditional tools.

We compared a series of software-extracted measurements to traditional measurements taken with a tape. Although there were some high individual differences, the mean differences, those average over all individuals, ranged from 6 mm (.25 inch) on neck circumference to 66 mm (2.6 inches) on sleeve length.

To judge the importance of those differences, we compared the mean differences to: 1) observer error for traditional techniques; 2) tailors' judgments about how close the measurements need to be; and 3) the size grade for men's dress coats and trousers.

The most functional criterion, in this context, is the size grade because it directly impacts the system's ability to assign the correct size. By this criterion, ARNScan is successful on all dimensions except cross shoulder and sleeve length. Software engineers are addressing those dimensions as of this writing.

We developed linear discriminant functions to assign garment sizes based on the dimensions extracted from the whole body scans. We found that using more dimensions results in increased size prediction accuracy. This suggests fundamental limitations to the usual approach, based on size selection charts which contain only 3 or 4 dimensions.

Finally, we examined anthropometric changes which occur in association with Marine Corps basic training. Many recruits lost weight, but the biggest changes were reductions in a number of torso circumferences, indicating a loss of body fat, and relative increase in muscle. Over 95% of recruits experienced some change in body dimensions, and many of these changes were larger than the garment grade in dress clothing. This means that a garment issued at the beginning of training would be incorrectly sized for the recruit at the end of training.

We compared the anthropometric characteristics of those recruits who dropped out of training with those who were still in training on the last week. The primary anthropometric characteristic of those who did not complete training was a relatively larger waist size. This information should not be used to screen out recruits, as it is not a 100% accurate predictor of basic training success. However, it may be used to identify those recruits who might benefit from a special diet or special exercise programs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

PREFACE

This document is the final technical report of one of a series of inter-related projects assembled under the title, *Standardized Measurement Procedures*. It is Apparel Research Network (ARN) project T1P1 of the Design and Development Focus Group.

T1P1 activities are included in ARN supertask Measurement and Pattern Generation 1 (MPG-1). MPG-1 overall objectives are to reduce pre-production time and cost in the acquisition of military dress clothing items, and to reduce the demand for special measurement (made-to-order, and custom) garments. The long-term benefits of MPG-1 will be to produce better fitting garments and decrease alterations.

The overall focus of MPG-1 is to improve the processes of taking traditional measurements (i.e., taken with a tape measure)and using those measurements to improve the fit and timeliness of special measurement orders. Other projects in MPG-1 include: 1) the development of expert systems to take special measurement order data and automatically create patterns; 2) the creation of pre-altered patterns and size selection routines to speed the processing of special orders; and 3) the development of an electronic order form, which allows customers at remote locations to provide sound body measurements to increase the likelihood of a special measurement garment fitting the first time. In the first phase of this effort, reported as *Reconciling Anthropometric and Tailoring Measurements for Clothing Design*, (T1P1 Phase 1, May, 1997), we examined the differences between the way tailors take measurements, and the way anthropologists take the same measurements. The focus of that study was to bridge the significant gap between methods, so that the special measurement expert systems and electronic order forms would be able to make use of the large military anthropometric data bases which have been created by anthropologists.

The direction of Measurement and Pattern Generation 2 (MPG-2), on the other hand, was towards making use of cutting edge technology to gather information on body size, instead of using the traditional tape measure. In that supertask, measurements are extracted from 3-D scan images of humans. The extracted measurements will ultimately feed expert systems for the creation of special measurement patterns and can be used for garment size selection.

This report, on the activities of T1P1 Phase 2, is very much a bridge between MPG-1 and MPG-2. In it we describe efforts to tie the measurements extracted from the scan images to measurement taken from the same individuals using tape measures and other traditional tools. Since the extracted measurements will ultimately be used in clothing design or selection, it is critically important to understand how the extracted measurements are the same as, or are different from, the traditional measures used by the clothing industry.

These activities also represent, in a sense, a continuation of a project in MPG-2, *Automating Information Extraction From 3-D Scan Data* (July, 1998). That earlier report detailed our first efforts at validating the measurements extracted from scan images. The test subjects there were civilians, and it was done in a laboratory setting. This project uses military subjects, and was conducted in at a military installation under conditions similar to those which might be used by a fully functioning system.

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. Mr. Addleman is the supertask coordinator for MPG-2. The weight data were collected by Steven Paquette, Research Anthropologist at U.S. Army Natick Research Development and Engineering Center, and the author is grateful for this contribution.

The author also wishes to thank Anthropology Research Project, Inc. staff for their contribution to this report. James Annis assisted with data collection; Mary E. Gross performed the statistical analyses; Shirley E. Kristensen prepared data for analysis; Belva Hodge prepared the final version of the report for publication; and Ilse O. Tebbetts edited the final document.

STANDARDIZE MEASUREMENT PROCEDURES
PHASE II: VALIDATION OF MEASUREMENTS – MARINE CORPS TEST

INTRODUCTION

The Apparel Research Network (ARN), funded by the Defense Logistics Agency, is engaged in a multi-year effort to improve the stocking and issuing of military clothing items. One approach being tested is the use of a whole body 3-D digitizer to collect body size information from new recruits with a view toward correctly issuing off-the-shelf dress uniform items. At present, the approach is to use the body scan data to generate traditional-style anthropometric dimensions which, in turn, inform a garment size selection algorithm to choose the proper size. While there are many variables which affect the success or failure of this approach, one critical variable is the accuracy with which the 3-D digitized points representing the surface of a recruit's body are translated into anthropometric dimensions. This report documents a field test in which Marine recruits from the recruit depot at San Diego (MCRD-San Diego) were measured with traditional tools, and were also digitized with a Cyberware Whole Body Scanner (WB-4). The data analysis consists of comparisons between the traditionally measured dimensions, and the same dimensions extracted from the scans. The dimensions are extracted from the scan data with software written for this project. Its name is ARNScan.

As this is a development effort, ARNScan continues to improve in functionality and in accuracy. Therefore, this work needs to be viewed as a snapshot – an assessment of the software's capabilities at a specific point in time. The version used for this effort was release 7.3. The capabilities of the software in that version include: automatic segmentation, and automatic identification of all dimensions. The automatic waist identification was not particularly reliable in this release, so a manual extraction routine was also provided. For the manual waist, the operator would use the mouse to identify the waist landmark, and then the software would extract the waist measurement using the landmark. In subsequent versions of the software, we expect the automatic waist to be improved sufficiently that operator intervention will not be required.

The Phase 2 portion of Anthropology Research Project's (ARP's) effort for the San Diego Field Test consisted of three main tasks. First, we collected traditional measurement data to compare against dimensions derived from ARNScan software. This information helped validate and improve subsequent versions of ARNScan. Second, we studied the changes in body size which occur during the Marine recruit's basic training. We scanned recruits at three points in their training schedule (T-0, T-19 and T-60, where T refers to *training day* and the numeral refers to the specific numbered day in the training cycle). This will aid future versions of ARNScan in selecting the correct final size for a recruit whose body may be rapidly changing. As an added benefit, these data will also help Marine clothing designers in creating patterns with sufficient alterability for today's recruits and will help MCRD-San Diego with some current issuing problems they have. Third, we investigated the relationship between garment size and body size with the goal of predicting the correct garment size based on a recruit's body dimensions.

ARNScan MEASUREMENT EXTRACTION VALIDATION

Data Collection

Dr. Bruce Bradtmiller and James Annis traveled to Monterey, CA in March 1998 to participate in the San Diego Field Test dress rehearsal. During that exercise, we modified some measurement and landmarking techniques, and created a landmark transfer device for the Acromion landmarks. Most important, we made sure that each team member had clear responsibilities, and we verified that we could process subjects at the rate of one per minute. The San Diego ARN team collected anthropometry using both traditional and automated (ARNScan) methods on each recruit over three sessions.

In late March, Bradtmiller and Annis traveled to San Diego to collect the first round of actual data. For these two trips, we measured new recruits just as they arrived at MCRD-San Diego, at T-0. Annis placed a waist belt on each recruit to mark the waist (the belt was removed before scanning). He also marked each shoulder (acromion) and the first knuckle on the thumb, where the Marine's shirt sleeve ends. The marking was done before each recruit was scanned. Each drawn mark was further identified by a paper dot. After scanning, Bradtmiller measured seven dimensions on each recruit. They were neck circumference, cross-shoulder, shoulder to wrist (for sleeve length), chest circumference, waist circumference, hip (seat) circumference, and crotch height (for trouser inseam). These dimensions were specifically chosen because they are important in garment sizing and in issuing correct sizes. During data analysis, they were eventually correlated with the actual sizes issued.

We let the pace of the scanner set the pace of traditional measurement, so we processed recruits at approximately one per minute. It should be noted that this is a significantly faster pace than usual. As a result, we expected our measurement error for traditional measurements to be higher than usual. To test this, we processed ten subjects twice, so we would be able to identify the level of our measurement error.

Over the course of the four data collection days (2 days each for 2 weeks), 319 recruits were processed. Ten of these were repeated for the measurement error test. We also processed ten recruits in the Physical Training Platoon, and repeated each of those.

During April, Bradtmiller and Annis continued data collection on the T-19 and T-20 days of Marine basic training. These two days are jointly referred to as T-19. On the two trips, 213 recruits were processed. Annis placed landmarks for the traditional anthropometric measuring as well as for verification of the automated landmarking features of ARNScan. Bradtmiller measured the same seven dimensions as were measured on T-0.

Note that substantially fewer subjects (213) were processed in April than in March (319). There are three reasons for this: (1) some individuals dropped out of training, (2) some individuals were delayed in training, so they were not present on T-19 with their entering group, and (3) the training schedule of one entire platoon was altered so that it was unavailable during the time we were there. Those individuals who dropped out of the Marines are lost to us forever. Those individuals who were delayed for medical reasons, physical conditioning, or other reasons are lost to us as well. They were still at MCRD-SD, but since their training was, in effect, on pause, they passed T-19/T-20 and T-60 at times other than when we were available to measure and scan them. It is possible that some were delayed enough to be passing through T-19 garment issue while we were there for T-60 measuring/scanning, but they would have had incomplete datasets. The final group, the platoon with the re-ordered training schedule, was not available to us during T-60 as we had hoped, so they too are lost to us. The data for individuals in any one of these groups are good for software validation, but they could not be used in the study of garment size, or in the longitudinal study.

Finally, during the T-19 data collection, we gathered the garment issue size for the dress coat, the long-sleeve dress shirt, and the blue and green dress trousers. These data are critical in validating ARNScan's size assignment algorithms.

The results of the validation of size selection can be compared with the "as-is" size selection process currently used by the Marines. Bradtmiller and Annis collected this "as-is" data earlier in the spring for use as a benchmark to assess whether ARNScan is more effective than the current approach.

In June, we collected the final data from the last week of basic training (T-60) for those recruits we had measured on T-0 and T-19. Although there were some dropouts between T-19 and T-60, the number of dropouts was much lower than between T-0 and T-19. In all, we measured 186 recruits for the T-60 sessions.

Data Entry And Editing Procedures

We first entered all the demographic, traditional measurement, and garment size data into a database. We edited the anthropometric data from both T-0 and T-19 using a statistical approach similar to that incorporated in the Electronic Order Form error checking. This editing catches potential instrument misreading errors, as well as potential data entry errors. Fewer than 10 errors were identified and corrected.

After data collection in June, we edited the T-60 traditional anthropometric data, made corrections as appropriate, and provided the edited data sets to the project partners.

As the only project partner with data from all the sources, it was our responsibility to organize the data so they would be useful for all the researchers. This was particularly complicated because some scan subjects from the first session were not present (for a variety of reasons) for subsequent sessions. We spent time during July creating files suitable for data analysis. We created:

1. 1 file for each session with all subjects
2. 1 file for each session with only the subjects who were present for all 3 sessions (the "active" subjects)
3. 1 file for active subjects, containing data from all 3 sessions
4. 1 file with repeat measure subjects
5. 1 file of "drop" subjects, including those who dropped between sessions 1 and 2, and those who dropped between sessions 2 and 3.

Summary Statistics

We calculated summary statistics for subjects in all the files listed above. Statistics from the active recruits, Sessions 1, 2, and 3 are shown in Appendix A.

We calculated frequency tables for age and race for the active recruits. Naturally the race did not change from one session to another. We recognize that age may have changed between Session 1 and Session 2 or 3, but judged that those changes in age were not important from an anthropometric point of view. Age at Session 1 is therefore considered a recruit's age for all the analyses in this project. These demographic tables also appear in Appendix A.

Comparison Of ARNScan With Traditional Measurements

All measurement of humans is subject to error. This is due to subject movement, subject position, imprecision in the establishment of landmarks and inconsistent tape tension (traditional measurements only). The goal of this analysis was to determine whether ARNScan measurement error is within acceptable limits. First, the MCRD traditional measurements were subtracted from the ARNScan measurements to estimate interobserver error, where Dr. Bradtmiller was one observer and the scanner was another. We first computed basic summary statistics for the absolute differences between the traditional and the scanner-derived dimensions. The summary statistics are seen in Table 1. The word *Geo* following a dimension name indicates that the ARNScan measurement was calculated from the scan geometry, rather than from a marked landmark. The word *Man* following a dimension name indicates that the dimension location was manually selected. Neck Circ Geo N refers to a new algorithm for finding this measurement. Both the original and the new versions are reported.

While it is clear the minimum values are acceptable in every case (except possibly sleeve length), the maximum values are largely unacceptable. Except for neck, the mean values are also higher than we would like. We are working with ARNScan programmers to help identify the sources of the difficulties so these differences can be reduced in subsequent versions of ARNScan.

TABLE 1

Absolute Differences Between Traditional and ARNScan Measurements
(values in mm)

VARIABLE	N	MIN DIFF	MAX DIFF	MEAN DIFF
Chest Circ – Geo	199	0	101	32.3
Chest Circ – Geo 2	199	0	463	33.2
Cross Shoulder – Geo	199	1	216	20.8
Crotch Ht – Geo	199	0	334	10.8
Neck Circ – Geo	199	0	30	5.7
Neck Circ – Geo N	190	0	32	6.4
Seat Circ – Geo	199	1	79	26.3
Sleeve Length – Geo	199	11	130	66.5
Stature – Geo	69	0	52	25.5
Waist Circ NI – Geo	199	0	248	15.9
Waist Circ NI – Man	198	0	80	14.2

The traditional measurements are a practical basis for validating ARNScan measurements. The ideal level of ARNScan measurement error would be no greater than traditional measurement error. At MCRD-San Diego, one measurer (Dr. Bradtmiller) repeated measurements twice for a total of 25 randomly selected subjects from T-0 and T-19. The mean of the absolute value of the difference (MAD) for these repeated measures provides some indication of intraobserver error (error due to repeated measurements by one observer) that can be expected among traditional measurements. Observer error data obtained in the 1988 survey of 9,000 U.S. Army personnel (ANSUR) provide the actual interobserver traditional measurement error seen in a large-scale anthropometric survey (Gordon et al., 1989).

The clothing industry also provides us with useful information for validating ARNScan. Ease and per-size grade are important factors in proper size selection, and are therefore useful gauges of how "important" a given measurement difference is. For example, if an ARNScan measurement were an inch smaller than the "true" measurement, then ARNScan would select a size smaller than the correct size on a one-inch grade garment. The result is an improper fit. To make use of this gauge, three tailors provided us with their opinions on acceptable measurement error. We also estimated per-size grade from sizing tables prepared by Southern Polytechnic State University (Carol Ring).

We compared the ARNScan MAD to the MAD of the MCRD traditional measurements. We would expect them to have similar values if ARNScan measurements are comparable to traditional measurements. We also computed the standard deviation of the differences and the technical error of measurement (TEM) (Cameron, 1984) of the differences. These values are equivalent when there is no observer bias (i.e., the interobserver error is comparable).

Finally, we compared ARNScan observed errors to the tailors' errors and per-size grade values to determine whether ARNScan errors fall within these limits. This means if the measurement were wrong by more than this amount, the individual would be assigned the wrong size garment. T-0 Stature (Stature measured with feet in scan position) was used for the traditional measurement. Sleeve Length (traditional) was derived from Sleeve Outseam + 1/2 Cross Shoulder. With the exception of Stature, all the traditional and ARNScan measurements are from the T-19 session. Table 2 contains the ANSUR and MRCD observed errors.

Table 2 illustrates a number of points. First, with respect to the ability of humans to measure, the MCRD traditional anthropometry MAD is larger in every case than the ANSUR observer error. In the case of ANSUR, the measurers were performing their task on a daily basis, all day, for approximately one year. These values represent the work of extremely experienced measurers and, we believe, are close to the limits of human measuring ability. That the MCRD MAD is larger reflects the fact that this measurer (Bradtmiller) does not ordinarily measure on a daily basis. It should be noted, however, that the differences between the MCRD MAD and the ANSUR observer error are approximately 1/8 inch on chest, sleeve length and waist, and are less than that on all other dimensions. Thus the MCRD MAD basically represents very good human measurement.

TABLE 2

Measurement Error
(values in inches)

VARIABLE	COMPARISON ERRORS						MCRD OBSERVED ERRORS		
	MCRD Trad MAD	ANSUR Observer Error	Tailor 1	Tailor 2	Tailor 3	Grade	Diff SD	Diff TEM	ARNScan MAD
Chest Circ – Geo2	.409	.271	±.375	-.25 to +.5	±.5	1	.867	.718	.816
Cross Shoulder – Geo	.309	.230	±.375	±.25	±.25	—	.294	.218	.226
Crotch Ht – Geo	.271	.237	±.375	-.25 to +.5	±.5	2	.300	.228	.259
Neck Circ – Geo	.154	.129	±.25	±.25	±.25	—	.294	.218	.226
Seat Circ – Geo	.306	.163	±.375	-.25 to +.5	±.5	1	.628	.840	1.037
Sleeve Length – Geo	.397	.205	±.25	-.25 to +.5	±.5	—	.806	1.879	2.553
Stature – Geo	.177	.116	—	—	—	—	.549	.798	1.010
Waist Circ NI – Man	.309	.188	±.375	-.25 to +.5	±.5	1	.727	.538	.560

If the MCRD traditional MADs are compared with the tailor estimates, chest circumference and sleeve length are outside Tailor 1's estimates; sleeve length is the worst case. All dimensions except neck circumference are larger than the lower value of Tailor 2, but all except cross shoulder are within the upper value. All deltas are within the estimates of Tailor 3. With respect to grading, all except the cross shoulder delta are within the grading intervals.

The ARNScan MAD (in which the ARNScan value is compared to the traditional value) is larger than the human MAD in every case except crotch height. Thus for crotch height, we may conclude that ARNScan measures this dimension within the limits of human measuring expertise. For the other dimensions, the ARNScan difference from the traditional measure is more than the observer error for the traditional measurement. Comparing the ARNScan difference from traditional to the tailor's estimates, the difference is less than the tailor's require on crotch height and on neck. On the other dimensions, the ARNScan difference from traditional is more than the tailors would like. The garment grade is a somewhat more forgiving criterion. Here, the ARNScan traditional difference is more than the garment grade only on cross shoulder and sleeve length. For the other dimensions, the difference would have placed an individual in the correct size anyway.

Comparison Of ARNScan With Natick Validation Study

In December 1997, a preliminary validation test was conducted by ARN personnel at the U.S. Army Natick Research Development and Engineering Center (Bradtmiller, 1998). It was the first independent test of the accuracy of ARNScan software. The Natick validation test and the San Diego validation test were conducted under somewhat different guidelines. Based on discussion with the partners prior to the Natick tests, we determined to do the traditional measures using ANSUR techniques, with the exception of waist, which was placed by the subject.

By the time of the San Diego study, the final scan posture had been determined. To minimize our impact on marine recruit processing, we determined that the traditional measures there should be taken with the subject in the scan posture. Because of the posture difference, the sleeve length could not be measured using the ANSUR method, and had to be calculated instead as a sleeve outseam plus one-half the cross-shoulder measure.

Hip was measured in the same manner, except that having the feet spread 30cm might increase the value slightly over the Natick validation method. Waist was measured according to the Marine clothing manuals, at the top of the hipbone (iliocristale), which was not comparable to the Natick method. Finally, crotch height was measured to the lowest point in the crotch (mimicking the scan method), and so would be a shorter value than the Natick value. Chest, cross shoulder, and neck were measured in the same way in both studies.

The comparisons are shown in Table 3. The shaded cells show which study had the lower difference between ARNScan and the traditional measure. It should be noted that some of the ARNScan algorithms from the earlier version relied on operator input, whereas all the current dimensions except waist were automatically determined. Nevertheless, it may be useful for the ARNScan programmers to review the procedures used in the two versions where the Natick validation differences are lower.

TABLE 3

Natick Validation Study Compared with San Diego Results, Session 2 (Scan – Traditional Deltas) Shaded cells = better results

VARIABLE	NATICK VALIDATION					SAN DIEGO RECRUITS				
	ARN-Scan Algo-rithm	N	Mean Abs Value of Diff	SD of Diff	TEM of Diff	ARN-Scan Algo-rithm	N	Mean Abs Value of Diff	SD of Diff	TEM of Diff
Chest Circ	B1	60	1.035	.982	.924	GEO2	183	.816	.867	.718
	B2	70	.771	.804	.706	GEO2	183	.816	.867	.718
Cross Shldr	B2	70	.516	.605	.493	GEO	196	.772	.715	.658
Crotch Ht	B2	70	.421	.504	.387	GEO	195	.259	.300	.228
Hip Circ	B1	70	.445	.533	.454	GEO	199	1.037	.628	.840
Neck Collar	B1	67	.398	.632	.446	GEO	199	.226	.294	.218
Sleeve Lgth	B1	70	.830	1.429	1.020	GEO	168	2.553	.806	1.879
	B2	37	2.300	1.348	1.879	GEO	168	2.553	.806	1.879
Waist Circ	B1	70	.510	.734	.520	MAN	198	.560	.727	.538
	B2	65	.960	.858	.842	MAN	198	.560	.727	.538

Summary

We tested the ARNScan software by comparing a series of extracted measurements to traditional measurements taken with a tape. For some *individuals* there were no differences on some dimensions. On other *individuals*, however, there were significantly large differences ranging from 30 mm (1.25 inch) on neck circumference to 463 mm (18 inches) on chest circumference (method 2). Those high individual differences are clearly unacceptable. Considering the whole test sample, the comparison is much better. The mean differences, those average over all individuals, ranged from 6 mm (.25 inch) on neck circumference to 66 mm (2.6 inches) on sleeve length.

To determine whether these differences constitute a significant problem in the context of apparel design and sizing, we compared the mean differences to: 1) observer error for traditional techniques; 2) tailors' judgments about how close the measurements need to be; and 3) the size grade for men's dress coats and dress trousers.

The most functional criterion, in this context, is the size grade because it directly impacts the system's ability to assign the correct size. By this criterion, ARNScan is successful on all dimensions except cross shoulder and sleeve length. It is likely that as of this writing, continuing work on those algorithms will result in improved measurement extraction.

SIZE SELECTION ALGORITHMS

We calculated the overall size distribution of the four subject garments that we are focusing on in this project: the jacket, the dress shirt, the green trousers, and the blue trousers. The distribution of these sizes is given in Appendix B.

One of the ultimate goals of the ARNScan software is to correctly issue off-the-shelf garment sizes. One of our tasks was to develop algorithms that take the body measurements as input, and output a predicted garment size. Our experience in a number of fit tests for dress clothing and other items suggested that size selection is not a univariate, but a multivariate problem. We chose to use discriminant function analysis to develop size selection algorithms. This approach is not often used in traditional size selection charts, because it is computationally intense. However, since ARNScan was designed to work in a high-speed computing environment, the approach was ideal here.

Table 4 indicates all the measurements available for discriminant analysis. There are nine ARNScan and nine traditional variables, but only seven variables common to both. We opted to use all nine variables in order to give each analysis as much information as possible for discriminating between sizes. We also ran each analysis with the following variations: (1) with and without outliers as determined from bad ARNScan measurements, and (2) using only the variables used in the traditional size selection tables.

TABLE 4

Available Predictor Variables

ARNScan	TRADITIONAL
Chest Circ Geo2	Chest Circ
X-Shoulder Geo	X-Shoulder
Crotch Ht Geo	Inseam Length
Neck Circ Geo	Neck Circ
Seat Circ Geo	Hip Circ
Sleeve Inseam Geo	Sleeve Outseam
Sleeve Length Geo	Sleeve Length
Stature Geo	Stature (T-0)
Waist Circ Man	Waist Circ

The classification procedure generates a set of discriminant functions which provide the best discrimination between sizes. The functions work by establishing linear relationships between the variables given known size classification. These functions look similar to regression equations. The coefficients of the functions take into account the prior probability of being classified into a group and the cost of being misclassified. The prior probability is the proportion of observations within a size to the total sample size. If an observation is correctly classified into a size, then the cost is zero (no cost); otherwise, it is one.

Classification procedures usually are not error-free. First of all, we usually cannot collect data on an entire population, so there is always the risk that a new sample will have different results. Effective sampling can reduce that risk, of course. Furthermore, size groups may overlap when there isn't a clear distinction between the measured characteristics of the population. This is often the case with anthropometric data when the relationship between measurements, such as the surface curvature between them, is as important as the measurements themselves. Heights, lengths, breadths, and circumferences do not capture this relationship. In addition, groups often overlap with garments - some people can wear a 34 or a 36 equally well. Since no size prediction cannot achieve 100% accuracy, the goal of discriminant analysis is to minimize the size selection errors.

In Figure 1, hypothetical data for two sizes (1 and 2) are plotted along with approximate confidence ellipses. The boundary line is defined by a discriminant function of two predictor variables. It goes through a point midway between the two group means and provides a visual indication of the accuracy of the discrimination. Observations issued size 1 located on the size 2 side of the line would be misclassified. Likewise for observations issued size 2 located on the size 1 side of the line. In simple terms, a new observation is classified into the group that it is the "closest" to when compared to each of the group means.

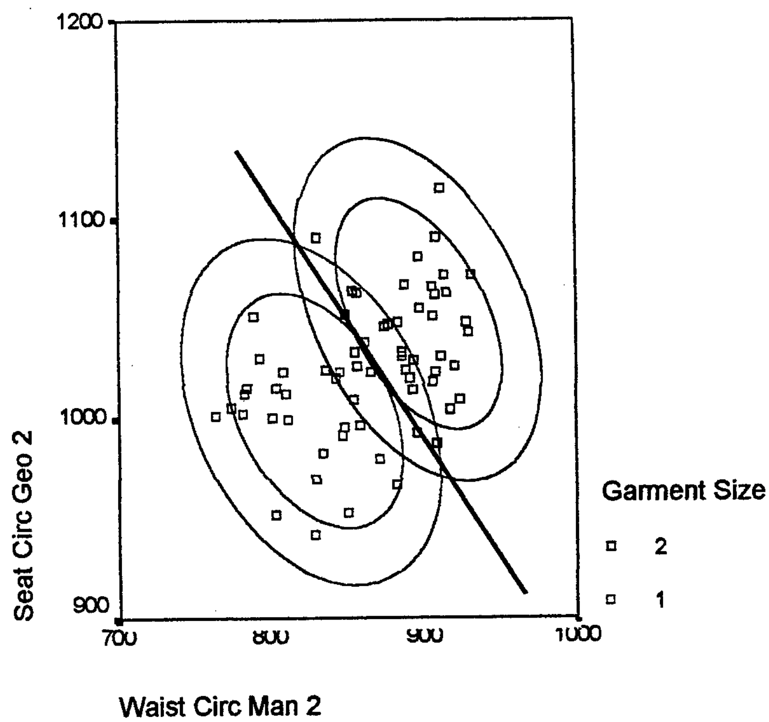

FIGURE 1

Discrimination between two size groups.

We would not recommend using discriminant functions in situations where size selection is done by hand. Too many calculations are involved. However, they are ideal in an automated environment. The coefficients can easily be stored in a matrix array, and the mathematical computations are simple and require little CPU time. More importantly, discriminant functions afford considerable flexibility in predictor variable types. Future generations of discriminant functions could include variables describing human body shape as well as dimensions.

Applying classification functions is fairly straightforward. Take the anthropometric data for one recruit and multiply each value by the appropriate coefficient in a size function. For example in Table 5, the chest circ geo2 measurement would be multiplied by .036154, the cross shoulder geo measurement by .562567, and so on for each of the dimensions. After all multiplication is completed, the products are summed to get the discriminant function score. A score is obtained for each size function. Finally, the scores are compared and the largest score determines the size classification.

Tables 5 through 7 provide an example for one recruit. The highlighted cell in the lower right corner of Table 5 is the score for the recruit using the function for size 32. The highlighted cell in the lower right corner of Table 6 is the score for the same recruit using the function for size 33. The highlighted cell in the lower right corner of Table 7 is the score for that recruit using the function for size 34. The scores are compared and the recruit is assigned to the size corresponding to the size function with the largest score. Since the score for the size 33 function is larger than that for the other two functions, this recruit would be assigned to size 33.

TABLE 5

Example: Linear Discriminant Function – Size 32

	Recruit 1 Data	Green Trouser Number Size 32	
		Coefficient	Product*
Chest Circ Geo2	985	0.036154	35.61145
Cross Shoulder Geo	472	0.562567	265.5315
Crotch Ht Geo	814	0.019565	15.92598
Neck Circ Geo	368	1.297906	477.6294
Seat Circ Geo	958	1.526877	1462.748
Sleeve Inseam Geo	493	0.555708	273.9641
Sleeve Lth Geo	853	-0.36863	-314.445
Stature Geo	1752	0.400704	702.0334
Waist Circ Man	784	1.117015	875.7401
(Constant)		-1880.78	-1880.78
Score = Sum of products			1913.958

* Product = measurement x coefficient

TABLE 6

Example: Linear Discriminant Function – Size 33

	Recruit 1 Data	Green Trouser Number Size 33	
		Coefficient	Product
Chest Circ Geo2	985	0.036576	36.02737
Cross Shoulder Geo	472	0.57968	273.609
Crotch Ht Geo	814	0.031488	25.63094
Neck Circ Geo	368	1.300134	478.4493
Seat Circ Geo	958	1.548875	1483.822
Sleeve Inseam Geo	493	0.578385	285.1439
Sleeve Lth Geo	853	-0.37608	-320.792
Stature Geo	1752	0.391948	686.6938
Waist Circ Man	784	1.163159	911.9166
(Constant)		-1946.17	-1946.17
Score = Sum of products			1914.329

* Product = measurement x coefficient

TABLE 7

Example: Linear Discriminant Function – Size 34

	Recruit 1 Data	Green Trouser Number Size 34	
		Coefficient	Product*
Chest Circ Geo2	985	0.04319	42.54256
Cross Shoulder Geo	472	0.596581	281.5863
Crotch Ht Geo	814	0.039596	32.23136
Neck Circ Geo	368	1.331936	490.1523
Seat Circ Geo	958	1.599844	1532.651
Sleeve Inseam Geo	493	0.635272	313.1889
Sleeve Lth Geo	853	-0.4345	-370.626
Stature Geo	1752	0.398737	698.5878
Waist Circ Man	784	1.192859	935.2018
(Constant)		-2046.59	-2046.59
Score = Sum of products			1908.925

* Product = measurement x coefficient

Tables 8 and 9 show the estimated accuracy of the linear discriminant function for the green trouser predicted number and length sizes. Tables 10 and 11 show the success rate for selecting both the correct number and length size, as well as for selecting either number only or length only. The row labeled "No Sizes" includes those individuals for whom neither number nor length was correct.

TABLE 8

Estimated Accuracy of Green Trouser Predicted Number Size

METHOD	VARIABLES	OUTLIERS INCLUDED		OUTLIERS EXCLUDED	
		Sample Size	Percent Accurate	Sample Size	Percent Accurate
Classification Functions Using ARNScan Data	Waist Circ Man Seat Circ Geo	196	63.3	B	B
	All 9 Variables	196	70.9	151	68.9
Classification Functions Using Traditional Data	Waist Circ Hip Circ	199	60.3	B	B
	All 9 Variables	199	65.8	B	B

TABLE 9

Estimated Accuracy of Green Trouser Predicted Length Size

METHOD	VARIABLES	OUTLIERS INCLUDED		OUTLIERS EXCLUDED	
		Sample Size	Percent Accurate	Sample Size	Percent Accurate
Classification Functions Using ARNScan Data	Stature Geo Crotch Ht Geo	197	67.5	193	68.9
	Stature Geo, Crotch Ht Geo, Predicted Number Size	196	74.5	151	75.1
	All 9 Variables	196	75.0	151	78.1
	All 9 Variables, Predicted Number Size	196	75.5	151	76.8
Classification Functions Using Traditional Data	Stature (T-0) Inseam Lth	199	69.8	B	B
	Stature (T-0), Inseam Lgth, Predicted Number Size	199	72.4	B	B
	All 9 Variables	199	77.4	B	B
	All 9 Variables, Predicted Number Size	199	77.9	B	B

TABLE 10

Green Trouser Success Rate for Joint Size Selection on Full Sample Using All Variables

Green Trouser Success Rate
(without predicted number size)

	N	%
Number and Length Size	107	54.6
Number Size Only	32	16.3
Length Size Only	41	20.9
No Sizes	16	8.2
Total	196	100.0

Green Trouser Success Rate
(with predicted number size)

	N	%
Number and Length Size	107	54.6
Number Size Only	32	16.3
Length Size Only	41	20.9
No Sizes	16	8.2
Total	196	100.0

The two portions of Table 10 are labeled "without number size" and "with number size". "With number size" refers to the case in which the number size discriminant function is computed first, and then the individual's predicted number size is used as an input variable (along with all the anthropometry) for the length discriminant analysis

Comparing Tables 10 and 11 shows that size prediction success decreases by using only key variables. This is intuitive – more information yields better size selection – and it confirms the results seen in Tables 8 and 9.

TABLE 11

Green Trouser Success Rate for Joint Size Selection on Full Sample Using Key Variables

Green Trouser Success Rate (without predicted number size)

	N	%
Number and Length Size	85	43.4
Number Size Only	39	19.9
Length Size Only	48	24.5
No Sizes	24	12.2
Total	196	100.0

Green Trouser Success Rate (with predicted number size)

	N	%
Number and Length Size	95	48.5
Number Size Only	29	14.8
Length Size Only	51	26.0
No Sizes	21	10.7
Total	196	100.0

Tables 12 and 13 repeat the analysis with the outliers excluded from the analysis. These 45 individuals were those identified by Beecher Research as having odd ARNScan values. It is interesting to note that removing these individuals does not improve the success of the discriminant function. Indeed, the success rate is slightly lower for the analysis with the key variables. This suggests that removing variability from the data set hinders the ability of the functions to "learn" about the best way to assign sizes.

Tables 14 and 15 show the estimated accuracy for the jacket predicted number and length sizes. Tables 16 through 19 show the success rate for jointly selecting the correct number and length size. It should be noted that the figures in Table 16 are counter-intuitive. Specifically, it appears that adding the predicted number size actually *decreases* the success of the function. This is because most of the accuracy of the complete size (number plus length) comes from correctly predicting the length (for example, see Tables 14 and 15). As the accuracy of measurement extraction improves, the number size prediction will improved. Then we would expect a more intuitive result of including or not including the number size in the linear discriminant function.

Tables 20 and 21 show the estimated accuracy for the shirt predicted neck and sleeve sizes. Tables 22 through 25 show the success rate for jointly selecting the correct neck and sleeve sizes.

TABLE 12

Green Trouser Success Rate for Joint Size Selection on Subsample Using All Variables

Green Trouser Success Rate
(without predicted number size)

	N	%
Number and Length Size	79	52.3
Number Size Only	25	16.6
Length Size Only	39	25.8
No Sizes	8	5.3
Total	151	100.0

Green Trouser Success Rate
(with predicted number size)

	N	%
Number and Length Size	79	52.3
Number Size Only	25	16.6
Length Size Only	37	24.5
No Sizes	10	6.6
Total	151	100.0

TABLE 13

Green Trouser Success Rate for Joint Size Selection on Subsample Using Key Variables

Green Trouser Success Rate
(without predicted number size)

	N	%
Number and Length Size	83	43.0
Number Size Only	38	19.7
Length Size Only	50	25.9
No Sizes	22	11.4
Total	193	100.0

Green Trouser Success Rate
(with predicted number size)

	N	%
Number and Length Size	93	48.2
Number Size Only	28	14.5
Length Size Only	52	26.9
No Sizes	20	10.4
Total	193	100.0

TABLE 14

Estimated Accuracy of Jacket Predicted Number Size

METHOD	VARIABLES	OUTLIERS INCLUDED		OUTLIERS EXCLUDED	
		Sample Size	Percent Accurate	Sample Size	Percent Accurate
Classification Functions Using ARNScan Data	Chest Geo X-Shoulder Geo	199	31.2	182	37.9
	All 9 Variables	198	48.0	151	54.3
Classification Functions Using Traditional Data	Chest Circ X-Shoulder	201	44.3	B	B
	All 9 Variables	201	51.2	B	B

TABLE 15

Estimated Accuracy of Jacket Predicted Length Size

METHOD	VARIABLE	OUTLIERS INCLUDED		OUTLIERS EXCLUDED	
		Sample Size	Percent Accurate	Sample Size	Percent Accurate
Classification Functions Using ARNScan Data	Stature Geo	199	69.3	198	70.7
	Stature Geo, Predicted Number Size	199	71.9	181	71.8
	All 9 Variables	198	75.8	151	74.8
	All 9 Variables, Predicted Number Size	198	73.7	151	74.2
Classification Functions Using Traditional Data	Stature (T-0)	201	73.6	–	–
	Stature (T-0), Predicted Number Size	201	74.6	–	–
	All 9 Variables	201	74.6	–	–
	All 9 Variables, Predicted Number Size	201	73.6	–	–

TABLE 16

Jacket Success Rate for Joint Size Selection on Full Sample Using All Variables

Jacket Success Rate
(without predicted number size)

	N	%
Number and Length Size	70	35.4
Number Size Only	25	12.6
Length Size Only	80	40.4
No Sizes	23	11.6
Total	198	100.0

Jacket Success Rate
(with predicted number size)

	N	%
Number and Length Size	67	33.8
Number Size Only	28	14.1
Length Size Only	79	39.9
No Sizes	24	12.1
Total	198	100.0

TABLE 17

Jacket Success Rate for Joint Size Selection on Full Sample Using Key Variables

Jacket Success Rate
(without predicted number size)

	N	%
Number and Length Size	42	21.1
Number Size Only	20	10.1
Length Size Only	96	48.2
No Sizes	41	20.6
Total	199	100.0

Jacket Success Rate
(with predicted number size)

	N	%
Number and Length Size	42	21.1
Number Size Only	20	10.1
Length Size Only	101	50.8
No Sizes	36	18.1
Total	199	100.0

TABLE 18

Jacket Success Rate for Joint Size Selection on Subsample Using All Variables

Jacket Success Rate
(without predicted number size)

	N	%
Number and Length Size	58	38.4
Number Size Only	24	15.9
Length Size Only	55	36.4
No Sizes	14	9.3
Total	151	100.0

Jacket Success Rate
(with predicted number size)

	N	%
Number and Length Size	58	38.4
Number Size Only	24	15.9
Length Size Only	54	35.8
No Sizes	15	9.9
Total	151	100.0

TABLE 19

Jacket Success Rate for Size Selection on Subsample Using Key Variables

Jacket Success Rate
(without predicted number size)

	N	%
Number and Length Size	51	28.2
Number Size Only	18	9.9
Length Size Only	77	42.5
No Sizes	35	19.3
Total	181	100.0

Jacket Success Rate
(with predicted number size)

	N	%
Number and Length Size	51	28.2
Number Size Only	18	9.9
Length Size Only	79	43.6
No Sizes	33	18.2
Total	181	100.0

TABLE 20

Estimated Accuracy of Shirt Predicted Number Size

METHOD	VARIABLES	OUTLIERS INCLUDED		OUTLIERS EXCLUDED	
		Sample Size	Percent Accurate	Sample Size	Percent Accurate
Classification Functions Using ARNScan Data	Neck Circ Geo X-Shoulder Geo	199	61.8	196	59.2
	All 9 Variables	198	68.2	151	66.2
Classification Functions Using Traditional Data	Neck Circ X-Shoulder	201	62.7	–	–
	All 9 Variables	201	67.2	–	–

TABLE 21

Estimated Accuracy of Shirt Predicted Length Size

METHOD	VARIABLES	OUTLIERS INCLUDED		OUTLIERS EXCLUDED	
		Sample Size	Percent Accurate	Sample Size	Percent Accurate
Classification Functions Using ARNScan Data	Sleeve Length Geo	199	46.2	171	45.6
	Sleeve Length Geo, Predicted Number Size	199	47.7	168	45.8
	All 9 Variables	198	53.5	151	55.6
	All 9 Variables, Predicted Number Size	198	54.0	151	58.9
Classification Functions Using Traditional Data	Sleeve Length	201	56.7	–	–
	Sleeve Length, Predicted Number Size	201	54.7	–	–
	All 9 Variables	201	55.7	–	–
	All 9 Variables, Predicted Number Size	201	55.7	–	–

TABLE 22

Shirt Success Rate for Joint Size Selection on Full Sample Using All Variables

Shirt Success Rate
(without predicted number size)

	N	%
Number and Length Size	69	34.8
Number Size Only	66	33.3
Length Size Only	37	18.7
No Sizes	26	13.1
Total	198	100.0

Shirt Success Rate
(with predicted number size)

	N	%
Number and Length Size	69	34.8
Number Size Only	66	33.3
Length Size Only	38	19.2
No Sizes	25	12.6
Total	198	100.0

TABLE 23

Shirt Success Rate for Joint Size Selection on Full Sample Using Key Variables

Shirt Success Rate
(without predicted number size)

	N	%
Number and Length Size	57	28.6
Number Size Only	66	33.2
Length Size Only	31	15.6
No Sizes	45	22.6
Total	199	100.0

Shirt Success Rate
(with predicted number size)

	N	%
Number and Length Size	57	28.6
Number Size Only	66	33.2
Length Size Only	33	16.6
No Sizes	43	21.6
Total	199	100.0

TABLE 24

Shirt Success Rate for Joint Size Selection on Subsample Using All Variables

Shirt Success Rate (without predicted number size)

	N	%
Number and Length Size	50	33.1
Number Size Only	50	33.1
Length Size Only	34	22.5
No Sizes	17	11.3
Total	151	100.0

Shirt Success Rate (with predicted number size)

	N	%
Number and Length Size	54	35.8
Number Size Only	46	30.5
Length Size Only	35	23.2
No Sizes	16	10.6
Total	151	100.0

TABLE 25

Shirt Success Rate for Joint Size Selection on Subsample Using Key Variables

Shirt Success Rate (without predicted number size)

	N	%
Number and Length Size	48	28.6
Number Size Only	51	30.4
Length Size Only	28	16.7
No Sizes	41	24.4
Total	168	100.0

Shirt Success Rate (with predicted number size)

	N	%
Number and Length Size	45	26.8
Number Size Only	54	32.1
Length Size Only	32	19.0
No Sizes	37	22.0
Total	168	100.0

Summary

Assimilating the size prediction results from all garments, we see that using more variables results in increased size prediction accuracy. This is important information because it suggests that enhancing ARNScan software to extract even more than the current 9 dimensions will improve accuracy further. It also suggests fundamental limitations to traditional approaches based on size selection charts.

Computing the complete size (number plus length) was done two ways. We first tried to assign the size using only the anthropometric variables. We also computed the discriminant function first for the number size, and then used the number size to help predict the length. The two step approach was more successful on trousers – there was a noticeable improvement by assigning the number size first. On upper body garments, the jacket and the shirt, there was essentially no difference between the two methods. It seems reasonable to use the two step approach since it improves the trousers, and has no deleterious effect on shirt and jacket.

For the jacket, removing outliers improves the accuracy (cf. Tables 16 and 18, and cf. Tables 17 and 19). On the trousers and shirt, however, removing outliers does not have any appreciable effect on accuracy (cf. Tables 10 and 12; cf. Tables 11 and 13; cf. Tables 22 and 24; cf. Tables 23 and 25). In any event, altering the software to exclude or not exclude outliers is not an issue in a fully implemented system. This is because there will be no way to identify outliers – they will simply become part of the proportion that is sized incorrectly.

LONGITUDINAL BODY CHANGES

It is well known that military recruits change body size and shape during basic training; indeed that is one of the goals of the process. What is less well known is the extent of those changes, and their character. Repeated measures analysis is useful for comparing observations over two or more occasions on the same set of subjects. We conducted a doubly multivariate repeated measures analysis (several observations over several occasions on each subject) to see if there were significant changes in the recruits' body sizes. We refer to changes occurring between sessions as longitudinal changes. Only variables with a sample size of 186 were included in the analysis, to avoid analytical problems due to missing data. Wilks' Lambda and Pillai's Trace multivariate F statistics indicate that body size, indeed, tended to change between sessions ($p=.000$).

As there is no easy way to analyze the multivariate results further, we examined univariate statistics to determine what changes occurred. We must use caution when interpreting these statistics, however, as univariate significance does not necessarily imply multivariate significance given the correlation between dimensions.

Table 26 contains the summary statistics for the mean differences between sessions. A negative difference indicates that the recruits tended to lose pounds or millimeters. Most change occurred between T-0 and T-19. Statistically significant changes (at $\alpha=.05$ are shaded. (Appendix C contains more detailed summary statistics along with significance test results.) Not surprisingly, the most significant changes appear in the chest, waist, and shoulders. Changes of less than half an inch (12.7 mm) may be statistically significant, but probably are not important for clothing applications.

TABLE 26

Comparisons of Mean Differences Between Sessions
(weight in pounds, all others in mm)

VARIABLE	SESSION 2-1		SESSION 3-2		SESSION 3-1	
	Mean	SD	Mean	SD	Mean	SD
Chest Circ	-16.3	29.97	-16.2	21.85	-32.7	39.51
Cross Shoulder	-2.8	14.59	-2.4	13.63	-5.2	17.85
Deltoid Ht	7.6	13.52	2.1	11.06	9.7	12.53
Hip/Seat Circ	-7.3	26.81	-13.5	22.06	-20.8	40.21
Inseam Length	2.2	13.25	-2.1	14.36	-.08	15.07
Neck Circ	-8.5	8.55	-6.3	6.88	-14.8	11.53
Shoulder Circ	-20.8	30.25	-8.2	18.20	-28.9	39.21
Sleeve Outseam	9.2	13.21	-5.1	11.78	4.1	12.76
Stature	—	—	—	—	.24	7.94
Waist Circ, Belt	-30.2	43.69	-23.1	29.21	-53.3	61.89
Waist Circ, O	-32.3	41.21	-12.3	27.20	-44.6	60.16
Waist Ht, O	2.7	6.28	.91	6.44	3.6	6.65
Weight	-4.4	8.53	-4.1	6.25	-8.5	12.76

Generally, circumferential dimensions tend to decrease by over an inch (25.4 mm) in the course of basic training. The average weight loss is relatively small, at 8.7 lbs. It should also be noted that the standard deviations for these are large, which indicates that some individuals experienced relatively large changes in these dimensions, while other individuals were basically unchanged.

Table 27 contains the 95% confidence interval for the mean difference of each dimension. These bounds provide an indication of how much variation in the mean value we can expect. Basically, we can expect the mean difference to fall within the confidence interval in 95 out of 100 independent surveys. Stature, inseam, and waist height omphalion are the only intervals that contain zero (i.e., do not change over time).

The purpose of this analysis is to compare the observed longitudinal changes to measurement errors accepted by tailors and observed between repeated measurements in session T-0. If the degree of longitudinal change falls within allowable error limits, then it is not of practical importance with respect to initial size issue. If the amount of change falls outside the limits, then these changes may have to be taken into consideration during the first fitting.

TABLE 27

Confidence Intervals for Mean Difference Over All Sessions
(weight in pounds, all others in mm)

	T-0 TO T-60	
	95% Confidence Interval of the Difference	
	Lower	Upper
Chest Circ	-37.93	-26.50
Cross Shoulder	-7.89	-2.84
Deltoid Ht	6.61	12.73
Hip/Seat Circ	-26.60	-14.99
Inseam Lth	-2.10	2.25
Neck Circ	-16.40	-13.07
Shoulder Circ	-38.49	-19.36
Sleeve Outseam	2.17	5.87
Stature	-0.51	1.48
Waist Circ	-62.00	-44.12
Waist Circ O	-59.30	-29.95
Waist Ht O	1.97	5.24
Weight	-10.30	-6.62

Table 28 shows the allowable error and the observed longitudinal changes side-by-side for easy comparison. It indicates that all the longitudinal changes are larger than those expected for repeated measurements within a session and larger than the ease allowed for by tailors. The longitudinal changes exceed the size grade for all of the measurements as well. The change in waist circumference is the most significant, indicating that many recruits could go down a size by the end of basic training

TABLE 28

Longitudinal Changes Compared with Allowable Error
(weight in pounds, all others in inches)

	ERROR	GARMENT COMPARISON VALUES				LONGITUDINAL CHANGES		
	T-0 Traditional Measurement Error (MAD)	Tailor						
		1	2	3	Grade	SD Signed Difference	TEM Signed Difference	Mean Absolute Difference
Chest Circ	0.41	±0.375	-.25 to +.50	±0.5	1	1.56	1.42	1.53
Hip/Seat Circ	0.31	±0.375	-.25 to +.50	±0.5	1	1.58	1.26	1.41
Neck Circ	0.15	±0.25	±0.25	±0.25	—	0.45	0.52	0.60
Shoulder Circ	0.18	—	—	—	—	1.54	1.35	1.46
Waist Circ	0.31	±0.375	-.25 to +.50	±0.5	1	2.43	2.26	2.42
Waist Circ O	0.29	±0.375	-.25 to +.50	±0.5	1	2.37	2.08	2.31
Weight	0.79	—	—	—	—	12.74	10.79	11.74

We continued our analysis using only the dimensions that changed by a half inch (12.7 mm) or more between T-0 and T-60. For these dimensions, we grouped individuals by the net change they experienced: loss, none, or gain. We then computed summary statistics for these groups. Table 29 shows that over 95% of the recruits experienced some type of body change. Losses were more common, occurring in nearly 70% or more of the recruits within each dimension. The magnitude of change (loss or gain) is proportional to the amount of variation observed in the dimensions.

TABLE 29

Summary Statistics Within Change Groups
(weight in pounds, all others in mm)

			N	N %	MEAN	SD	SE	MIN	MAX	MEDIAN
Chest Circ	Change	loss	146	78.50%	-45	34	3	-150	-1	-39
		none	3	1.60%	0	0	0	0	0	0
		gain	37	19.90%	17	13	2	1	50	15
	Group Total		186	100.00%	-32	40	3	-150	50	-25
Hip/Seat Circ	Change	loss	122	65.60%	-43	29	3	-123	-2	-39
		none	1	0.50%	0	.	.	0	0	0
		gain	63	33.90%	22	15	2	2	62	20
	Group Total		186	100.00%	-21	40	3	-123	62	-16
Neck Circ	Change	loss	169	90.90%	-16	11	1	-55	-1	-15
		none	3	1.60%	0	0	0	0	0	0
		gain	14	7.50%	3	2	0	1	7	4
	Group Total		186	100.00%	-15	12	1	-55	7	-13
Shoulder Circ	Change	loss	48	71.60%	-46	32	5	-106	-2	-39
		gain	19	28.40%	14	12	3	1	38	11
	Group Total		67	100.00%	-29	39	5	-106	38	-23
Waist Circ	Change	loss	146	78.50%	-73	54	4	-248	-1	-60
		none	1	0.50%	0	.	.	0	0	0
		gain	39	21.00%	20	16	3	1	62	16
	Group Total		186	100.00%	-53	62	5	-248	62	-40
Waist Circ O	Change	loss	44	65.70%	-79	44	7	-179	-13	-74
		none	1	1.50%	0	.	.	0	0	0
		gain	22	32.80%	21	16	3	1	67	19
	Group Total		67	100.00%	-45	60	7	-179	67	-42
Weight	Change	loss	132	71.00%	-14.2	10.3	0.9	-40.4	-0.1	-11.3
		gain	54	29.00%	5.6	4.1	0.6	0.2	15.7	4.3
	Group Total		186	100.00%	-8.5	12.7	0.9	-40.4	15.7	-7.3

Table 30 contains the 95% confidence intervals for expected longitudinal changes between T-0 and T-60. The lower and upper bounds indicate the range in which the mean change is expected to occur 95% of the time. Losses are more prevalent.

TABLE 30

95% Confidence Intervals for Expected Losses and Gains
(weight in pounds, all others in mm)

		T-0 TO T-60 95% Confidence Intervals for Losses and Gains Lower	Upper
Chest Circ	loss	-50.80	-39.73
	gain	12.21	21.15
Hip/Seat Circ	loss	-48.45	-37.88
	gain	18.32	26.06
Neck Circ	loss	-18.09	-14.89
	gain	2.28	4.43
Shoulder Circ	loss	-55.45	-36.76
	gain	8.47	20.48
Waist Circ	loss	-81.88	-64.16
	gain	15.12	25.49
Waist Circ O	loss	-92.13	-65.15
	gain	14.20	28.53
Weight	loss	-16.01	-12.45
	gain	4.50	6.77

Dropout Analysis

The acquisition of the longitudinal data allows us to ask other questions as well. One such question is: Are there any distinguishing anthropometric characteristics of those individuals who did not complete basic training with their entering platoon? This analysis addresses that issue. As noted above, there are any number of reasons one might drop behind the rest of the platoon during training, or drop out altogether. These include medical, psychological, and even bureaucratic reasons. The question of interest concerns those who are true dropouts – those who could not complete Marine Corps basic training. It was important, therefore to identify those who had dropped out, as opposed to those who were missing at T-60 because, for example, they had had dental work earlier during training. To sort out these individuals, we relied on the drill instructors assigned to each platoon. For the most part, they were able to indicate, by name, which recruits had actually dropped out. There are 48 individuals whose dropout status was unknown. They are analyzed separately. The summary statistics for those completing all of basic training are found in Tables 31, 32, and 33, and for those who were clearly dropouts, in Table 34. The dropouts are generally larger in size than those completing basic training, with much of the excess concentrated in the waist. Specifically, the dropouts are about 1.25 inches larger in the chest and the hip, but 2.25 larger in the waist. Interestingly, they are only 12 pounds heavier, on average, but the difference in weight is not evenly spread over the body. As another point of

TABLE 31

MCRD San Diego Recruits Completing Sessions 1,2,3
Session 1 Anthropometry
(weight in pounds, values in mm)

VARIABLE	N	MIN	MAX	MEAN	SD
Chest Circ 1	186	853	1192	986.99	76.42
Cross Shoulder 1	186	342	499	437.30	25.60
Hip/Seat Circ 1	186	830	1130	972.51	65.53
Inseam Length 1	186	686	928	781.66	41.12
Neck Circ 1	186	332	434	378.71	19.72
Sleeve Outseam 1	186	523	750	626.33	32.13
Stature 1	186	1589	1982	1754.72	65.37
Waist Circ 1	186	694	1078	845.70	87.00
Weight 1	186	119.7	232.8	171.86	25.23

TABLE 32

MCRD San Diego Recruits Completing Sessions 1,2,3
Session 2 Anthropometry
(weight in pounds, values in mm)

VARIABLE	N	MIN	MAX	MEAN	SD
Chest Circ 2	186	845	1124	971.13	57.50
Cross Shoulder 2	186	361	490	434.49	22.52
Hip/Seat Circ 2	186	850	1094	964.49	48.87
Inseam Length 2	186	680	934	783.47	40.69
Neck Circ 2	186	328	407	370.01	15.73
Sleeve Outseam 2	186	528	744	635.52	30.97
Waist Circ 2	186	681	937	814.60	53.85
Weight 2	186	128.5	215.9	167.26	19.39

TABLE 33

MCRD San Diego Recruits Completing Sessions 1,2,3
Session 3 Anthropometry
(weight in pounds, values in mm)

VARIABLE	N	MIN	MAX	MEAN	SD
Chest Circ 3	186	849	1097	954.96	51.84
Cross Shoulder 3	186	369	490	432.12	23.71
Hip/Seat Circ 3	186	850	1049	951.01	40.47
Inseam Length 3	186	685	906	781.34	39.00
Neck Circ 3	186	324	405	363.74	15.23
Sleeve Outseam 3	186	532	743	630.12	30.70
Stature 3	186	1599	1969	1754.68	64.00
Waist Circ 3	186	671	916	791.62	43.71
Weight 3	186	125.0	213.4	163.17	17.215

TABLE 34

MCRD – Dropout San Diego Recruits
(Between Session 1 and Session 2)
(weight in pounds, values in mm)

VARIABLE	N	MIN	MAX	MEAN	SD
Chest Circ 1	29	850	1126	1018.52	74.27
Cross Shoulder 1	29	392	476	437.72	20.80
Hip/Seat Circ 1	29	861	1126	1004.90	74.21
Inseam Length 1	29	701	867	781.62	44.00
Neck Circ 1	29	346	410	375.21	16.86
Sleeve Outseam 1	29	557	676	630.97	29.55
Stature 1	29	1636	1871	1761.59	63.14
Waist Circ 1	29	693	1026	902.10	102.51
Weight 1	29	128.8	224.9	183.77	27.99

interest, those recruits with insufficient information to determine their status (Table 35) are even higher than the true dropouts on all the dimensions noted above. It may be that many of them are true dropouts as well.

TABLE 35

MCRD – Dropout San Diego Recruits – Insufficient Data to Determine Status
(Between Session 1 and Session 2)
(weight in pounds, values in mm)

VARIABLE	N	MIN	MAX	MEAN	SD
Chest Circ 1	48	894	1164	1022.19	76.47
Cross Shoulder 1	48	374	512	446.04	30.74
Hip/Seat Circ 1	48	860	1142	1008.58	69.74
Inseam Length 1	48	666	914	779.35	59.37
Neck Circ 1	48	336	418	386.02	19.13
Sleeve Outseam 1	48	549	716	626.98	39.12
Stature 1	48	1633	1950	1765.17	77.45
Waist Circ 1	48	730	1094	906.13	105.62
Weight 1	48	134.4	240.4	184.94	27.04

We conducted a MANOVA to compare the recruits with unknown completion status (the 'lost' platoon, those with missing data, and those who took medical leave or were assigned to another platoon) to those who succeeded and those who failed basic training. We used the following nine traditional measurements taken at T-0 as a basis for comparison: weight, stature, neck circumference, cross shoulder, sleeve outseam, chest circumference, waist circumference, hip circumference, and inseam. The multivariate F-statistics (Pillai's, Hotellings', and Wilks') indicate that there is at least one significantly different group (p=.0001).

To determine which group(s) is (are) different, we output the linear discriminant functions (LDF) and computed their scores (values) for each individual. In general, the number of functions is equal to the number of groups minus 1. Since we have three groups, we have two functions. The first function describes the axis that maximizes the variation between groups. The second function is perpendicular to the first. Table 36 contains the coefficients for the LDFs. The coefficients on Function 1 indicate that differences are largely due to a contrast between weight and torso measurements with the rest of the measurements. This means that one group does not carry as much weight in the torso as another group.

TABLE 36

Linear Discriminant Function Coefficients

VARIABLE	FUNCTION 1	FUNCTION 2
Chest Circ	-0.546	0.214
Cross Shoulder	0.003	-0.337
Hip/Seat Circ	-0.617	-0.873
Inseam	-0.654	0.384
Neck Circ	-0.786	-1.218
Sleeve Outseam	0.083	0.310
Stature	0.494	-0.953
Waist Circ	1.487	-0.695
Weight	0.868	2.265

Summary statistics for the scores (Table 37) show that the active group is the cause of the significant difference. The mean of function 1 for the active group is lower than that for the other two groups. This indicates that waist circumference and weight tend to be smaller for the active group and thus have a smaller impact on the function scores. The dropout and unknown groups do not appear to be significantly different from each other.

TABLE 37

Summary Statistics for Linear Discriminant Function Scores

STATUS	COUNT	SCORE	MIN	MAX	MEAN	SD
Unknown	48	Function 1	268.62	631.35	439.78	101.67
		Function 2	-2858.71	-2475.03	-2681.68	93.72
Active	202	Function 1	213.09	613.63	377.33	75.22
		Function 2	-2821.37	-2423.13	-2621.48	88.83
Drop	29	Function 1	270.57	601.65	442.63	101.52
		Function 2	-2821.15	-2459.73	-2657.59	100.10

Differences Between Successes And Others

Based on the analysis described above, we combined the data for the dropout and unknown groups and renamed the resulting group "Other." The reason for doing this is that by increasing the group sample size we increase our ability to find a significant difference between groups when one truly exists. Table 38 contains summary statistics for two groups, active and other. The "other" group includes recruits who dropped out of training and those who, for one reason or another, did not finish training with their originally assigned platoon.

TABLE 38

Summary Statistics for Active and Other Recruits
(weight in pounds, all others in mm)

VARIABLE		N	MEAN	SD	SE	95% CONFIDENCE INTERVAL FOR THE MEAN Lower Bound	Upper Bound	MIN	MAX
Chest Circ 1	Active	202	986.87	77.24	5.43	976.15	997.58	820	1192
	Other	77	1020.81	75.18	8.57	1003.74	1037.87	850	1164
	Total	279	996.23	78.03	4.67	987.04	1005.43	820	1192
Cross Shoulder 1	Active	202	437.17	25.60	1.80	433.62	440.72	342	499
	Other	77	442.91	27.57	3.14	436.65	449.17	374	512
	Total	279	438.76	26.23	1.57	435.66	441.85	342	512
Hip/Seat Circ 1	Active	202	971.50	65.22	4.59	962.45	980.55	830	1130
	Other	77	1007.19	70.99	8.09	991.08	1023.31	860	1142
	Total	279	981.35	68.62	4.11	973.26	989.44	830	1142
Inseam Length	Active	202	782.82	41.01	2.89	777.13	788.51	666	928
	Other	77	780.21	53.80	6.13	768.00	792.42	686	914
	Total	279	782.10	44.82	2.68	776.82	787.38	666	928
Neck Circ 1	Active	202	378.25	20.10	1.41	375.46	381.04	332	434
	Other	77	381.95	18.94	2.16	377.65	386.25	336	418
	Total	279	379.27	19.82	1.19	376.93	381.60	332	434
Sleeve Outseam 1	Active	202	625.65	32.37	2.28	621.16	630.14	523	750
	Other	77	628.48	35.66	4.06	620.39	636.58	549	716
	Total	279	626.43	33.27	1.99	622.51	630.35	523	750
Stature 1	Active	202	1755.12	65.11	4.58	1746.08	1764.15	1589	1982
	Other	77	1763.82	71.98	8.20	1747.48	1780.16	1633	1950
	Total	279	1757.52	67.06	4.01	1749.61	1765.42	1589	1982
Waist Circ 1	Active	202	844.46	86.50	6.09	832.45	856.46	691	1078
	Other	77	904.61	103.80	11.83	881.05	928.17	693	1094
	Total	279	861.06	95.29	5.71	849.83	872.29	691	1094
Weight 1	Active	202	171.50	25.46	1.79	167.97	175.03	114.4	232.8
	Other	77	184.50	27.22	3.10	178.32	190.68	128.8	240.4
	Total	279	175.09	26.55	1.59	171.96	178.22	114.4	240.4

We conducted a MANOVA on the anthropometry of the active group comparing it to that of the other group. The multivariate F-statistics (Pillai's, Hotellings', and Wilks') indicate the two groups are significantly different (p=.0001).

Table 39 contains the coefficients for the linear discriminant function. The coefficients indicate that the effect of waist circumference and weight become more important in discriminating between the groups. Table 40 contains summary statistics for the LDF scores. The active group tends to have lower scores than the other group, because they have smaller waists with respect to the rest of their bodies.

TABLE 39

Linear Discriminant Function Coefficients

VARIABLE	FUNCTION 1
Chest Circ	-0.546
Cross Shoulder	0.003
Hip/Seat Circ	-0.617
Inseam	-0.654
Neck Circ	-0.786
Sleeve Outseam	0.083
Stature	0.494
Waist Circ	1.487
Weight	0.868

TABLE 40

Summary Statistics for Linear Discriminant Function Scores

STATUS	SCORE	COUNT	MIN	MAX	MEAN	SD
Active	Function 1	202	596.55	1042.28	779.45	85.74
Other	Function 1	77	653.16	1055.76	850.00	112.10

Where linear discriminant functions are helpful to describe the nature of the differences between groups, linear classification functions (LCF) are useful for predicting group membership of new observations. This means that the function can be used to estimate, based on T-0 measurements, whether a recruit is likely to complete training or fall into the other group. Table 41 provides these classification functions for predicting graduation status for new recruits.

TABLE 41

Classification Function Coefficients*

	STATUS	
VARIABLE	Pass	Fail
Chest Circ	1.155	1.148
Cross Shoulder	.482	.484
Hip/Seat Circ	2.342	2.336
Inseam Length	-.368	-.381
Neck Circ	2.738	2.714
Sleeve Outseam	.297	.297
Stature	1.408	1.416
Waist Circ	.09515	.109
Weight, lbs	-12.062	-12.046
(Constant)	-2522.981	-2522.982

*Fisher's linear discriminant functions

To apply these functions, take the T-0 anthropometric data for one recruit and multiply each value by the appropriate coefficient in each column of the table. For example, weight would be multiplied by -12.062, stature by 1.408, and so on for each of the dimensions. After each of the multiplications, the answers are summed to get the discriminant function score. The multiplications are performed twice – once for the first function and once for the second. The recruit is assigned to the group corresponding to the function with the largest score. Table 42 contains an example for one subject. Since the score for the pass function is larger than that for the fail function, this subject would be assigned to the pass group. These functions were approximately 78% accurate in predicting the correct graduation status for the San Diego recruits.

TABLE 42

Example of How to Use Linear Classification Functions for One Subject

	PASS				FAIL			
	Measure		Coefficient		Measure		Coefficient	
Chest Circ	+	(1022.0	*	1.155)	+	(1022.0	*	1.148)
Cross Shoulder	+	(485.0	*	.482)	+	(485.0	*	.484)
Hip/Seat Circ	+	(1032.0	*	2.342)	+	(1032.0	*	2.336)
Inseam Length	+	(787.0	*	-.368)	+	(787.0	*	-.381)
Neck Circ	+	(434.0	*	2.738)	+	(434.0	*	2.714)
Sleeve Outseam	+	(636.0	*	.297)	+	(636.0	*	.297)
Stature	+	(1795.0	*	1.408)	+	(1795.0	*	1.416)
Waist Circ	+	(929.0	*	.095)	+	(929.0	*	.109)
Weight, Lbs.	+	(205.5	*	-12.062)	+	(205.5	*	-12.046)
(Constant)	+			-2522.981	+			-2522.982
Score	=			2532.724	=			2530.215

A word of caution: this technique should not be used to "weed out" recruits. The accuracy, while good, is not 100%. The most appropriate use of this technique would be to identify recruits who might benefit from extra attention during training.

Summary

We examined anthropometric changes which occur in association with Marine Corps basic training. The focus of the examination was whether the body size changes need to be considered when assigning garment size.

We found that although many recruits lost weight, the average loss was not as great as one might suppose – between 8 and 9 pounds. However, there was considerable reduction in a number of torso circumferences, indicating a loss of body fat, and relative increase in muscle. Over 95% of recruits experienced some change in body dimensions, and many of these changes were larger than the garment grade in dress clothing. This means that a garment issued at the beginning of training would be incorrectly sized for the recruit at the end of training.

We also compared the anthropometric characteristics of those recruits who dropped out of training, with those who were still in training on the last week. The primary anthropometric characteristic of those who did not complete training was a relatively larger waist size.

CONCLUSION

This project had three primary goals: to examine the relationship between human body measurements taken with traditional tools (tapes, etc.) and those extracted from whole body scans with ARNScan software; to examine an approach to garment size selection based on multivariate analysis of dimensions extracted from whole body scans; and to examine anthropometric changes in Marine Corps recruits during the course of basic training.

We tested the ARNScan software by comparing a series of extracted measurements to traditional measurements taken with a tape. Although there were some high individual differences, the mean differences, those average over all individuals, ranged from 6 mm (.25 inch) on neck circumference to 66 mm (2.6 inches) on sleeve length.

To judge the importance of those differences, we compared the mean differences to: 1) observer error for traditional techniques; 2) tailors' judgments about how close the measurements need to be; and 3) the size grade for men's dress coats and dress trousers.

The most functional criterion, in this context, is the size grade because it directly impacts the system's ability to assign the correct size. By this criterion, ARNScan is successful on all dimensions except cross shoulder and sleeve length. Software engineers are addressing those dimensions as of this writing.

We developed linear discriminant functions to assign garment sizes based on the dimensions extracted from the whole body scans. We found that using more dimensions results in increased size prediction accuracy. This is important information because it suggests that enhancing ARNScan software to extract even more than the current 9 dimensions will improve accuracy further. It also suggests fundamental limitations to traditional approaches based on size selection charts.

Computing the complete size (number plus length) was done two ways. We first tried to assign the size using only the anthropometric variables. We also computed the discriminant function first for the number size, and then used the number size to help predict the length. The two step approach was more successful on trousers – there was a noticeable improvement by assigning the number size first. On upper body garments, the jacket and the shirt, there was essentially no difference between the two methods. It seems reasonable to use the two step approach since it improves the trousers, and has no deleterious effect on shirt and jacket. A significant advantage to the linear discriminant function approach is that the functions can be made to "learn" from actual garment sizes assigned by the fitters and tailors. With the Marines' high recruit flow, the system accuracy should rapidly improve.

Finally, we examined anthropometric changes which occur in association with Marine Corps basic training. Many recruits lost weight, but the biggest changes were reductions in a number of torso circumferences, indicating a loss of body fat, and relative increase in muscle. Over 95% of recruits experienced some change in body dimensions, and many of these changes were larger than the garment grade in dress clothing. This means that a garment issued at the beginning of training would be incorrectly sized for the recruit at the end of training.

We also compared the anthropometric characteristics of those recruits who dropped out of training, with those who were still in training on the last week. The primary anthropometric characteristic of those who did not complete training was a relatively larger waist size.

REFERENCES

Bradtmiller, Bruce 1998. *Automating Information Extraction from 3-D Scan Data.* Final Technical Report, Project T2P5, for Defense Logistics Agency, Ft. Belvoir, VA.

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 A

SUMMARY ANTHROPOMETRIC STATISTICS AND DEMOGRAPHIC FREQUENCY TABLES

TABLE A-1

Recruits Who Completed All 3 Sessions - Session 1

DIMENSION	N	MIN	MAX	MEAN	SE	SD	SKEWNESS	KURTOSIS
Calf Circ 1	119	310	445	378.94	2.51	27.42	.201	-.266
Calf Ht 1	119	297	401	348.11	1.79	19.49	.178	.082
Chest Circ 1	186	853	1192	986.99	5.60	76.42	.507	-.353
Deltoid Ht 1	67	1229	1554	1350.72	6.69	54.78	.700	1.720
Hip/Seat Circ 1	186	830	1130	972.51	4.80	65.53	.314	-.649
Inseam Length 1	186	686	928	781.66	3.02	41.12	.371	.696
Neck Circ 1	186	332	434	378.71	1.45	19.72	.078	-.289
Shoulder Circ 1	67	1038	1348	1186.60	8.53	69.84	-.002	-.397
Sleeve Outseam 1	186	523	750	626.33	2.36	32.13	.385	.999
Stature 1	186	1589	1982	1754.72	4.79	65.37	.236	.539
Stature2 1	67	1601	1978	1754.01	7.52	61.56	.554	1.642
Thigh Circ 1	119	479	706	590.83	4.72	51.45	.393	-.569
Waist Circ 1	186	694	1078	845.70	6.38	87.00	.367	-.878
Waist Circ, O 1	67	716	1032	863.33	11.24	91.98	.219	-1.243
Waist Ht, O 1	66	958	1215	1059.71	5.80	47.11	.507	.930
Weight 1	186	119.7	232.8	171.862	1.850	25.229	.245	-.771
Cross Shoulder 1	186	342	499	437.30	1.88	25.60	-.389	.511

TABLE A-2

Recruits Who Completed All 3 Sessions - Session 2

DIMENSION	N	MIN	MAX	MEAN	SE	SD	SKEWNESS	KURTOSIS
Chest Circ 2	186	845	1124	971.13	4.22	57.50	.242	-.234
Cross Shoulder 2	186	361	490	434.49	1.65	22.52	-.199	.168
Deltoid Ht 2	67	1233	1559	1358.30	6.55	53.63	.778	2.048
Hip/Seat Circ 2	186	850	1094	964.49	3.58	48.87	.241	-.489
Inseam Length 1	186	686	928	781.66	3.02	41.12	.371	.696
Lateral Malleolus Ht 2	119	57	94	74.36	.67	7.33	.209	.228
Mid-Patella Circ 2	119	345	431	386.80	1.82	19.89	.122	-.586
Mid-Patella Ht 2	119	449	568	496.84	2.25	24.58	.345	-.251
Neck Circ 2	186	328	407	370.01	1.15	15.73	.121	-.360
Shoulder Circ 2	67	1016	1277	1165.82	6.57	53.80	-.163	.027
Sleeve Outseam 2	186	528	744	635.52	2.27	30.97	.177	.790
Waist Circ 2	186	681	937	814.60	3.95	53.85	.291	-.615
Waist Circ, O 2	67	735	973	830.99	7.56	61.87	.401	-.804
Waist Ht, O 2	67	957	1227	1062.22	5.91	48.34	.628	1.312
Weight 2	186	128.5	215.9	167.263	1.422	19.388	.180	-.663

TABLE A-3

Recruits Who Completed All 3 Sessions - Session 3

DIMENSION	N	MIN	MAX	MEAN	SE	SD	SKEWNESS	KURTOSIS
Chest Circ 3	186	849	1097	954.96	3.80	51.84	.380	-.102
Cross Shoulder 3	186	369	490	432.12	1.74	23.71	-.280	-.178
Deltoid Ht 3	67	1231	1565	1360.39	6.83	55.91	.684	1.837
Hip/Seat Circ 3	186	850	1049	951.01	2.97	40.47	.085	-.438
Inseam Length 3	186	685	906	781.34	2.86	39.00	.233	.246
Neck Circ 3	186	324	405	363.74	1.12	15.23	.124	-.054
Shoulder Circ 3	67	1034	1251	1157.67	5.88	48.11	-.405	-.234
Sleeve Outseam 3	186	532	743	630.12	2.25	30.70	.297	.857
Stature 3	186	1599	1969	1754.68	4.69	64.00	.160	.269
Waist Circ 3	186	671	916	791.62	3.21	43.71	.314	-.029
Waist Circ, O 3	67	736	922	818.70	5.59	45.75	.319	-.717
Waist Ht, O 3	67	959	1219	1063.13	5.84	47.82	.638	1.018
Weight 3	186	125.0	213.4	163.168	1.262	17.205	.129	-.453

TABLE A-4

Recruits Who Completed All 3 Sessions – Race

RACE	N	%
White	115	61.8
Black	12	6.5
Hispanic	44	23.7
Asian/Pacific Islander	4	2.2
Native American	8	4.3
Other	3	1.6
Total	186	100.0

TABLE A-5

Recruits Who Completed All Sessions – Age

AGE	N	%
17	8	4.3
18	39	21.0
19	50	26.9
20	31	16.7
21	16	8.6
22	11	5.9
23	12	6.5
24	5	2.7
25	5	2.7
26	2	1.1
27	2	1.1
28	2	1.1
29	3	1.6
Total	186	100.0

APPENDIX B

Garment Size Distribution

TABLE B-1

Recruits - Session 2 - Jacket Sizes

Jacket Size	Jacket Length					Total
	XS	S	R	L	XL	
29			1			1
36	1	3		1		5
37	1	6	10			17
38		8	18	8		34
39	1	7	17	8	1	34
40	1	8	14	8	1	32
41		1	16	13	3	33
42	1	6	13	9	1	30
43		6	1	6	1	14
44		1	4	6		11
46			2			2
Total	5	46	96	59	7	213

TABLE B-2

Recruits - Session 2 - Shirt Sizes

Shirt Neck	Shirt Sleeve								Total
	31	32	33	34	35	36	37	38	
14.0				1					1
14.5		1	2	7		2			12
15.0	1	3	11	5	6	5	1	2	34
15.5		2	14	28	19	3	1	1	68
16.0			5	23	23	14	3		68
16.5			1	6	10	4	3	3	27
17.0					1	1	1		3
Total	1	6	33	70	59	29	9	6	213

TABLE B-3

Recruits - Session 2 - Green Trouser Sizes

Waist Size	Green Trouser Length				Total
	S	R	L	XL	
29		3			3
30		7			7
31	3	15	7		25
32	1	28	6	1	36
33	5	16	15	2	38
34	2	9	16	3	30
35		10	16	1	27
36		6	29	5	40
38		1	4		5
Total	11	95	93	12	211

TABLE B-4

Recruits - Session 2 - Blue Trouser Sizes

Waist Size	Blue Trouser Length				Total
	S	R	L	XL	
29		3			3
30		5			5
31	3	17	4		24
32	2	25	11	1	39
33	5	17	16	2	40
34	2	8	15	3	28
35		10	17	1	28
36		6	28	5	39
38		1	4		5
Total	12	92	95	12	211

APPENDIX C

Summary Statistics and Significance Tests for 3 Measuring Sessions

TABLE C-1

Summary Statistics for T-0 to T-19
(weight in pounds, all others in mm)

	N	MEAN	SD	MIN	MAX	MEDIAN
Chest Circ Delta	186	-16	30	-84	51	-13
Cross Shoulder Delta	186	-3	15	-47	43	-2
Deltoid Ht Delta	67	8	14	-29	37	7
Hip/Seat Circ	186	-7	27	-75	46	-5
Inseam Lth Delta	186	2	13	-46	43	3
Neck Circ Delta	186	-8	9	-37	14	-8
Shoulder Circ Delta	67	-21	30	-83	44	-19
Sleeve Outseam Delta	186	9	13	-23	45	9
Waist Circ Delta	186	-31	44	-153	64	-24
Waist Circ (O) Delta	67	-32	41	-117	41	-31
Waist Ht (O) Delta	66	3	6	-16	23	2
Weight Delta	186	-4.3	8.3	-24.3	12.8	-2.8

TABLE C-2

One-Sample Test for T-0 to T-19
(weight in pounds, all others in mm)

DIFFERENCE	TEST VALUE =0	df	SIGNIFICANCE	MEAN	95% CONFIDENCE INTERVAL OF THE DIFF	
	t		(2-TAILED)	DIFF	Lower	Upper
Chest Circ Delta	-7.313	185	0	-16.04	-20.37	-11.71
Cross Shoulder Delta	-2.575	185	0.011	-2.75	-4.85	-0.64
Deltoid Ht Delta	4.591	66	0	7.58	4.28	10.88
Hip/Seat Circ Delta	-3.729	185	0	-7.31	-11.18	-3.44
Inseam Lgth Delta	2.273	185	0.024	2.20	0.29	4.12
Neck Circ Delta	-13.538	185	0	-8.46	-9.7	-7.23
Shoulder Circ Delta	-5.622	66	0	-20.78	-28.15	-13.4
Sleeve Outseam Delta	9.385	185	0	9.09	7.18	11.00
Waist Circ Delta	-9.453	185	0	-30.62	-37.01	-24.23
Waist Circ (O) Delta	-6.424	66	0	-32.34	-42.4	-22.29
Waist Ht (O) Delta	3.508	65	0.001	2.71	1.17	4.26
Weight Delta	-6.999	185	0	-4.261	-5.462	-3.06

TABLE C-3

Summary Statistics for T-19 to T-60 (weight in pounds, all others in mm)

	N	MEAN	SD	MIN	MAX	MEDIAN
Chest Circ Delta	186	-16	22	-96	44	-16
Cross Shoulder Delta	186	-3	13	-44	34	-4
Deltoid Ht Delta	67	2	11	-29	24	2
Hip/Seat Circ Delta	186	-13	22	-80	30	-13
Inseam Lth Delta	186	-2	14	-46	69	-2
Neck Circ Delta	186	-6	7	-27	15	-5
Shoulder Circ Delta	67	-8	18	-56	26	-7
Sleeve Outseam Delta	186	-5	12	-41	22	-4
Waist Circ (O) Delta	67	-12	27	-80	38	-7
Waist Circ Delta	186	-22	28	-139	40	-20
Waist Ht (O) Delta	67	1	6	-18	15	1
Weight Delta	186	-4.2	6	-22.1	9.4	-3.1

TABLE C-4

One-Sample Test for T-19 to T-60 (weight in pounds, all others in mm)

DIFFERENCE	TEST VALUE=0	df	SIGNIFICANCE (2-TAILED)	MEAN DIFF	95% CONFIDENCE INTERVAL OF THE DIFF	
	t				Lower	Upper
Chest Circ Delta	-10.119	185	0	-16.17	-19.33	-13.02
Cross Shoulder Delta	-2.705	185	0.007	-2.62	-4.53	-0.71
Deltoid Ht Delta	1.547	66	0.127	2.09	-0.61	4.79
Hip/Seat Circ Delta	-8.359	185	0	-13.48	-16.67	-10.30
Inseam Lgth Delta	-2.026	185	0.044	-2.13	-4.20	-0.06
Neck Circ Delta	-12.444	185	0	-6.27	-7.26	-5.27
Shoulder Circ Delta	-3.666	66	0	-8.15	-12.59	-3.71
Sleeve Outseam Delta	-5.892	185	0	-5.08	-6.77	-3.38
Waist Circ Delta	-11.004	185	0	-22.44	-26.46	-18.42
Waist Circ (O) Delta	-3.697	66	0	-12.28	-18.92	-5.65
Waist Ht (O) Delta	1.157	66	0.252	0.91	-0.66	2.48
Weight Delta	-9.569	185	0	-4.202	-5.07	-3.34

TABLE C-5

Summary Statistics for T-0 to T-60
(weight in pounds, all others in mm)

	N	MEAN	SD	MIN	MAX	MEDIAN
Chest Circ Delta	186	-32	40	-150	50	-25
Cross Shoulder Delta	186	-5	17	-70	46	-4
Deltoid Ht Delta	67	10	13	-24	36	11
Hip/Seat Circ Delta	186	-21	40	-123	62	-16
Inseam Lgth Delta	186	0	15	-57	53	0
Neck Circ Delta	186	-15	12	-55	7	-13
Shoulder Circ Delta	67	-29	39	-106	38	-23
Sleeve Outseam Delta	186	4	13	-36	41	4
Stature Delta	186	0	7	-18	19	1
Waist Circ Delta	186	-53	62	-248	62	-40
Waist Circ (O) Delta	67	-45	60	-179	67	-42
Waist Ht (O) Delta	66	4	7	-18	27	4
Weight Delta	186	-8.5	12.7	-40.4	15.7	-7.3

TABLE C-6

One-Sample Test for T-0 to T-60
(weight in pounds, all others in mm)

DIFFERENCE	TEST VALUE=0	df	SIGNIFICANCE (2-TAILED)	MEAN DIFF	95% CONFIDENCE INTERVAL OF THE DIFF	
	t				Lower	Upper
Chest Circ Delta	-11.114	185	0	-32.22	-37.93	-26.50
Cross Shoulder Delta	-4.196	185	0	-5.37	-7.89	-2.84
Deltoid Ht Delta	6.316	66	0	9.67	6.61	12.73
Hip/Seat Circ Delta	-7.071	185	0	-20.80	-26.60	-14.99
Inseam Lgth Delta	0.068	185	0.946	0.0753	-2.10	2.25
Neck Circ Delta	-17.459	185	0	-14.73	-16.40	-13.07
Shoulder Circ Delta	-6.039	66	0	-28.93	-38.49	-19.36
Sleeve Outseam Delta	4.285	185	0	4.02	2.17	5.87
Stature Delta	0.954	185	0.341	0.48	-0.51	1.48
Waist Circ Delta	-11.712	185	0	-53.06	-62.00	-44.12
Waist Circ (O) Delta	-6.072	66	0	-44.63	-59.30	-29.95
Waist Ht (O) Delta	4.407	65	0	3.61	1.97	5.24
Weight Delta	-9.062	185	0	-8.463	-10.306	-6.621