APPLIED PHYSICAL ANTHROPOLOGY IN THE U.S. ARMY

By Brian D. Corner and Claire C. Gordon

In recent decades anthropometry has declined, except for applied anthropology. Instead of measuring the bodies of the last remnants of aboriginal populations, anthropometrists measure military personnel and civilians in order to design railroad and airplane seats and space suits. Doctors of Philosophy have become tailors to the new age of science.
C. Coon, *The Origin of Races* (New York: Alfred A. Knopf, 1962)

Brian Corner and Claire Gordon

Coon's criticism of physical anthropology's shift away from more scientific pursuits may be true, but the demand for applied research and its sophistication continue to grow. In a world where products from toothbrushes to luxury sedans are touting ergonomic design, it is physical anthropologists who provide designers and engineers with the anthropometric measurements necessary to create a smooth interface between a product and the curves and swells of the human body.

Robert White wrote of "wearing" not only clothes but automobiles and houses as well ("Some Applications of Physical Anthropology," *Journal of the Washington Academy of Sciences* 42[1952]:65-71). Consumers find a greater level of comfort and efficiency if the automobile or house "fits." From a manufacturing point of view, however, it is not practical to provide every customer with a custom-made product. To maximize consumer accommodation while minimizing production costs, designers and manufacturers turn to physical anthropologists whose expertise in describing variability in body size and shape is used to create a range of product sizes or to determine the level of adjustability needed to fit the consumers.

The task of accommodating a large, anthropometrically variable population is not easy. Trade-offs are made between the number of sizes, or the range of adjustability, and the cost of production. In the commercial world, clothing and equipment are often designed and marketed to very specific target populations. There are other user groups where such tight management is not available—where as much as 95 percent of the population must be accommodated with a limited set of sizes for one or two designs. The U.S. Army is one such group. The need to accommodate one of the largest and most heterogeneous user populations has made the Army a leader in applied physical anthropology for over fifty years.

Running jokes about uniforms two sizes too small or overly large helmets aside, anthropometry is serious business in the Army. Consider the challenge of fitting over 500,000 soldiers in three sizes of chemical/biological protective mask. And the fit must be good, for the consequences of a poor fit are dire.

The Army supports seven anthropologists; two are government employees, and the others work through a support contractor, GEO-CENTERS, INC. All levels of training are represented, from B.A. to Ph.D. Almost everyone who has come to work in Army Anthropometry had little previous experience in the applied world. Most were trained in traditional physical anthropology: skeletal biology, osteology, primate anatomy, forensics, some genetics, a smattering of statistics.

The Army can trace its history of applied anthropology back to the 1860s (Claire Gordon and Karl Friedl, "Anthropometry in the US Armed Forces," in S. K. Ulijaszek and C. G. N. Mascie-Taylor, eds., *Anthropometry: The Individual and Population* [Cambridge: Cambridge University Press, 1994] pp. 178-210). However, the modern era of applied anthropology in the Army really begins with World War II, when, for the first time, sophisticated statistical analyses of body dimensions were used to support the design of clothing, personal equipment, and workstation layout.

Beginning in 1940, as the Army expanded rapidly in preparation for war, a number of sizing and outfitting problems became apparent. The problems were most acute in the Army Air Corps (now the U.S. Air Force) where work space was at a premium and adequate equipment fit a necessity for survival.

As Damon and Randall wrote, "War is a notorious accelerator of the practical trends in a science..." (Albert Damon and Francis Randall, "Physical Anthropology in the Army Air Forces," *American Journal of Physical Anthropology* 2[1944]:293-316). The Air Corps turned to the science of physical anthropology for measurement techniques and statistical methods to address problems of equipment fit and workstation accommodation. Ernest Hooton lent his considerable expertise in the early 1940s. He was soon joined by Albert Damon and Francis Randall. Other anthropologists of note who participated in Army anthropology include Alice Brues, Paul Baker, C. Loring Brace, and Robert White.

Today the center for Army anthropology is the U.S. Army Soldier Systems Command, Natick Research, Development, and Engineering Center in Natick, Massachusetts. Anthropologists employed by the Army conduct basic and applied research in biological anthropology and biomechanics to enhance the safety and performance of the individual soldier.

The heart of Army anthropology is the anthropometric data collected during measurement surveys. Surveys of Army personnel have been carried out periodically since the 1920s. The latest, in 1987-1988, resulted in one of the most complete anthropometric data sets to date. (The next major anthropometric survey is not anticipated until well into the next century.)

The 1988 ANthropometric SURvey (ANSUR) data consist of measurements of 132 body dimensions from over 9,000 soldiers. In addition to standard anthropometrics, extensive data on hands were compiled from detailed photographs, and three-dimensional coordinates were obtained from anatomically defined landmarks on the face and head. Analyses of ANSUR data are published by the government in a series of technical reports which include general summary statistics, correlation matrices, partial regression equations, and bivariate tables. Data are available to researchers through the National Technical Information Service or the Defense Technical Information Center.

Anthropometric data are used to establish design, sizing, and tariffing criteria for virtually all items of Army clothing and individual equipment. (A tariff is the calculation of the number of individual items per size needed to supply a given population, and is how the military computes purchasing costs.) Anything that the soldier carries or wears, from headgear to footwear, body armor to dress uniforms, has some anthropometric input. The data are also used to establish work space criteria and to solve ergonomic problems in aircraft cockpits, tank crew stations, hard shelters, and tentage. Requirements documents and military standards, handbooks, and specifications include anthropometric data as well.

After fifty years of effort quantifying and describing biological variation in the U.S. Army population, one may think that there is little left to know. That might be true if the Army population remained static, but the Army is constantly changing. Over the past twenty years or so, the Army has moved from a predominantly white male draft force to an ethnically diverse male and female volunteer population. Demographic shifts are compounded by the increased integration of women into traditionally male roles. Today, equipment systems are designed to fit 90-95 percent of the Army population from the smallest women to the largest men. To give you an idea of the range of body sizes that must be accommodated, the shortest woman in the 1988 data base is 4' 8" while the tallest man is 6' 8".

As the demographic diversity of the Army expands, anthropologists work to document the effect increased variation has on accommodation rates and general fit of a soldier's clothing and equipment. For example, initial research into ethnic- and gender-specific variation in body dimensions indicates that race and gender both significantly influence anthropometric distributions for nearly all of the 164 variables examined (Robert A. Walker, "Race, Ethnicity, and Human Engineering," in Claire Gordon, ed., *Race, Ethnicity, and Applied Bioanthropology*, NAPA Bulletin no. 13, pp.7-33, 1993). Furthermore, results show that the pattern of ethnic-related differences is not the same for men and women.

In response to the increased number of women in almost all Army roles, anthropologists have developed integrated sizing systems. We are all familiar with sizing systems; jeans are sized on waist circumference and inseam length, hats by head circumference, and so on. Because the Army was predominantly male in the past, many of the sizing systems were based on male body dimensions, leading to problems of fit for women.

An integrated sizing system takes variation in body dimensions of men and women into account when it is created, and the measurements used to predict size are as gender neutral as possible. An example is the single size Battledress Uniform (BDU)—the loose fitting camouflage uniform soldiers wear for day-to-day business. The integrated sizing system for the BDU uses circumference at the shoulder rather than the typical chest circumference to size the coat, and circumference around the buttock rather than waist circumference to size the pant. This allows men and women to be fit equally well. (Claire Gordon, "Anthropometric

Sizing and Fit Testing of a Single Battledress Uniform for U.S. Army Men and Women," in R. L. Barker and G. C. Coletta, eds., *Performance of Protective Clothing* [Philadelphia: American Society for Testing and Materials, 1986] pp. 581-592).

In addition to improving fit, gender integrated sizing reduces the number of sizes needed to accommodate the Army population. Fewer uniforms to manufacture and stock means lower costs to the tax payers. A gender integrated approach was also used for new glove and anti-gravity trouser designs, and it is being applied to new clothing and equipment items whenever possible.

Technological developments also drive continued anthropological research in the Army. Today, a soldier's gear includes such sophisticated equipment as laser-aiming devices, night vision goggles, and heads-up displays for communication and navigation. (Heads-up displays are small computer screens that attach to a soldier's helmet, so that the soldier can either look ahead focusing beyond the screen, or take a quick look at the information on the screen, say a topographic map, without looking away from the situation in front of him or her.) Creating systems that fit securely so as to maximize soldier performance demands closer tolerances between body and equipment, and analyses must keep up with the complex fit of equipment systems. Hence, multivariate statistics are replacing bivariate approaches as more anthropometric information is used to provide accurate models of the body.

Recent developments in three-dimensional (3D) imaging technology have provided physical anthropologists with new methods for collecting anthropometric data. Structured light- and laser-based digitizers are available for digitizing the surface of the head, feet, and the whole body.

The benefits of a 3D digitizing system are easily recognized. The speed and amount of data collected are improved over manual measurement; digitizing takes only seconds and provides a nearly infinite number of possible measurements. Another benefit relates to subject and data access. Most subjects measured with hand instruments are measured once and dismissed; they are rarely available for repeat observations. Digital images last forever, theoretically, and can be revisited at any time. In addition, 3D digitizing allows us to capture geometric information. With 3D images, we not only get distance measurements, but we have the spatial relationships between the measurements. Hence, we have an anatomically accurate 3D form around which equipment and clothing can be designed.

As promising as 3D digitalizing technology is, there are some hurdles that must be overcome. One of the most significant is that images cannot be touched. Many of the landmarks or other points of reference used in measurement are related to specific sites on the skeleton. They are located by palpating overlying soft tissue to feel the bumps and furrows of the bone. There is also a certain amount of "touch" with the measuring instruments. How much tension to put on a steel tape, or how gently calipers are laid on the skin, affect the distance obtained. In fact, even the most experienced of us goes through several practice sessions to minimize interobserver error prior to fieldwork.

Before 3D digitizing can be an effective replacement for manual measurement, the issues of feel and touch, among others, must be addressed. The Army is developing protocols for subject preparation, landmark identification, image editing, and data extraction. Studies comparing standard and image-based measurements are underway. Although hand measurements will likely never be completely replaced, the use of 3D digitizers is growing rapidly, and this will be a major data collection mode in the foreseeable future.

Collecting 3D images to extract anthropometric measurements is one application for digitizer data. Creating solid models for engineers to use in computer-aided design is another. Modeling the human-equipment interface is yet a third potent application.

Computer-aided fit-testing (CAFT) is a means of quantifying the relationship between the geometry of people and the geometry of equipment. For example, many interacting parameters affect helmet fit. One factor is how well a helmet shell coincides with the shape of the head. Quantifying the compatibility of head and helmet geometry is next to impossible in the real world. Using CAFT, however, a virtual helmet can be tried on a series of virtual heads, accurate in anatomical detail, and the differences in geometries displayed. That information can be fed back into the helmet design, if necessary, and the CAFT procedure repeated until a satisfactory design is achieved.

Not only can single pieces of equipment be evaluated, but whole systems can be checked for compatibility. Helmet, protective goggles, and ear protection, for instance, can be checked for interferences. The range of CAFT applications is limited only by the ability to model equipment, and the potential cost savings in development time and prototype production is dramatic.

Anthropologists working for the Army are also involved in biomechanical analysis. Clothing and equipment impose restrictions on the ability of a soldier to move. Impeding movement reduces performance. Biomechanical analysis helps us to understand the restrictions and alter designs so that their impact on movement is minimized.

In another application of image-gathering technology, anthropologist/biomechanists are employing a computerized video motion system to record soldiers' movements (running, walking, climbing stairs, jumping, etc.). Segmental and angular displacements and accelerations of the trunk and limbs are calculated from video data. Analyses of alterations to locomotor mechanics under various clothing and equipment conditions are used to identify and characterize optimal design configurations for clothing, protective equipment, and load-bearing systems.

Physical anthropologists work with engineers to enhance soldier safety and performance by providing data which characterize the broad range of gender and population variability in human form. In many respects this is a good melding of two disciplines. Engineers tend to think in terms of hard numbers—*the* average head length or *the* smallest chest circumference—so they can design the hardware soldiers will carry. Anthropologists bring some fuzziness to the numbers by introducing population variability that must be accommodated so the equipment functions as designed for all soldiers.

Army anthropologists play a critical role in the design and function of all equipment for the soldier. The Army also provides anthropometric support for items developed by the Navy and Marine Corps. The Air Force is the only other branch of the military that has its own anthropology group, which is similar in size to that of the Army.

We would like to say that the kind of human factors engineering support an anthropologist can provide is utilized by numerous other government agencies and private industry as well as by the military. Unfortunately, that is not the case. For example, a government agency gearing up for a large study of personal protective equipment advertised recently for mechanical engineers and equipment designers, physiologists, and human factors psychologists, but no anthropologists. Nevertheless, a few physical anthropologists can be found in the auto, aviation, and biomedical appliance industries working as human factors engineers. Some work in the insurance industry analyzing accidents submitted for claims. In addition, there are a few small companies like Anthropology Research Project of Yellow Springs, Ohio, doing anthropometric contract work.

Unlike the more traditional areas in physical anthropology, there is no well-defined study track in applied physical anthropology. A student interested in applied work should be trained in anthropometric techniques, have a sound knowledge of statistics, and, more than anything else, get a good feeling for the level of contemporary human variability.

Applied physical anthropology may not be as high profile or as glamorous as other areas in the field, but it is challenging and rewarding. The challenge is to take a complex mix of information from many fields, such as engineering, clothing design, and product manufacture, and integrate anthropometry into the design process. The greatest reward is seeing the application of our research in a direct, tangible way.

Think about us the next time you get in your car; the results of our work are literally all around you.

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[The authors would like to thank Curtis Wienker, Corresponding Editor of *Practicing Anthropology,* for encouraging us to share our work with other applied anthropologists. We also thank the members of the Anthropology Group for their dedicated service: Ken Parham and Steve Paquette (U.S. Army Natick Research, Development, and Engineering Center) and Bob Woods, Sarah Donelson, Ann Carson, Henry Case, and Wendy Todd (GEO-CENTERS).]

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