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FINAL REPORT
March, 1975

BASIC BIOMECHANICAL PROPERTIES OF THE HUMAN NECK RELATED TO LATERAL HYPERFLEXION INJURY

Highway Safety Research Institute
The University of Michigan
Ann Arbor 48105

Prepared for:
Insurance Institute for Highway Safety
Watergate Six Hundred
New Hampshire Avenue, N.W.
Washington, D.C. 20037

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16. Abstract

Properties of the human neck which may influence a person's susceptability to "whiplash" injury during lateral impact have been studied in 96 normal subjects. Subjects were chosen on the basis of age, sex, and stature, and data were grouped into 6 primary categories based on sex (F,M) and age (18-24, 35-44, 62-74). Stature served as a secondary variable, with each group of 16 subjects being matched to obtain an average stature close to the 50th percentile for the category. The data include: measures of head, neck and body anthropometry in standing and normal seated positions; stretch reflex time of sternomastoid muscles; head/neck response to low-level acceleration; voluntary isometric muscle force in the lateral direction; and three-dimensional range of motion of the head and neck. Data are presented in a format applicable for biomechanical modeling of the seated human occupant and have been used in the MVMA-2D model adjusted for side impact at 10 and 30 mph to determine the influence of the measured properties on reducing "whiplash" injury susceptability.

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Additional assistance was provided by Dr. D. Hurley Robbins, Head, Biomathematics Department, HSRI, who advised on the mathematical modeling design and anthropometry measures useful to modeling; Dr. John Melvin, Head, Biomechanics Department, HSRI, who generously provided advice on instrumentation and data reduction problems; and Dr. Herbert Reynolds, physical anthropologist, Biomedical Department, HSRI, who suggested seated orthogonal photogrammetry measures and provided consultation on anthropometric measurements and techniques. The authors are grateful to the volunteer subjects from the Ann Arbor area, without whose willing participation this study could not have been conducted.

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SUMMARY

Basic properties of the human neck related to lateral hyperflexion injury were measured on a subject pool of 96 persons, balanced for sex, age, and stature, according to data from the U.S. Public Health Survey (1962). Subjects were grouped into six categories based on sex and age (18-24 years, 35-44 years, and 62-74 years). Within each subject group the stature was balanced (e.g., three tall, ten medium, and three short persons) to represent an average stature for that subject group.

Measurements taken included: sixty measures of traditional anthropometry, 24 anthropometry measures obtained by photogrammetry to describe the seated occupant, stretch reflex times of the sternomastoid muscle group resulting from lateral jerks to the head, neck muscle isometric strength in lateral flexion, and three-dimensional range of motion from photogrammetry of the six planar head motions (flexion, extension, right and left rotation, right and left lateral bend) and three head movements involving combinations of the planar motions. Range of motion results were calculated by digital computer programs and are expressed in Euler angle notation. Head acceleration during the reflex tests was measured by two biaxial pairs of accelerometers and the results were used to compute head angular acceleration. This provided a basis for comparison of computer simulations of the reflex tests with actual experimental results, and a determination of a more accurate value for the lateral static bending stiffness of the neck under small deformations. Results obtained for strength, reflex time, and lateral range of motion were used in the MVMA-2D model adjusted for side impact to simulate responses of the various subject groups to 10 and 30 mph side impacts.

While the primary and complete value of the data from this study can only be obtained from the numerous tables and figures contained in this report, the following presents some of the major achievements and results observed:

1. Traditional anthropometry measures indicate excellent matching of this study subject pool to that of both the sagittal plane study and the Public Health Service.

2. Locations of major body masses for the six subject categories were obtained from traditional anthropometry measures.

3. Three-dimensional photogrammetry techniques were successfully used in conjunction with traditional anthropometry measures to describe the seated automobile occupant. Locations of 38 measurements for each subject category have been determined and graphically displayed.

4. Three-dimensional orthogonal photogrammetry techniques have been used successfully to determine Euler-angle statistics for range of motion of the six subject groups. In general the ranges of motion were similar for males and females in the three planes (yaw, pitch, and roll) and showed a continuous decrease with age. The rate of decrease with age was greater for males than females. Greatest range of motion was found in the rotational plane (136.5° average for all subjects) while the smallest was in the lateral plane (71.0° average for all subjects). For the combination movements the amount of extension or flexion achievable after a full rotation was less than 50% of that attained without rotation,

while the amount of left lateral bend after full left rotation was unchanged.

5. Stretch reflex times of the right sternomastoid muscle group range from about 25 to 75 msec, with the overall average being 50.2 msec. Reflex times for the 62-74 year subject groups were about 15-25 percent longer than the 18-24 and 35-44 year groups. Males had slightly longer reflex times than females on the average (53.3 msec to 47.1 msec). Also, stretch reflex times for the sternomastoid muscle group in lateral flexion appear to be shorter than for the same muscle group in extension obtained in the sagittal plane study (50.2 msec compared to 71.7 msec, average for all subjects).

6. Females show muscle strengths considerably less than males. The greatest strengths were found for 35-44 year males and were nearly three times greater on the average than the smallest strengths found for the 62-74 year females. Both males and females show substantial decreases in muscle strength between the 35-44 and 62-74 year groups.

7. Appropriate values for the lateral static bending stiffness of the neck for small deformations have been determined by computer simulation of the reflex tests to be between 8 and 16 in-lb/degree, depending on the population segment.

8. Use of the experimental data of this study in the MVMA Two-Dimensional Crash Victim Simulation, Version 3, has resulted in the following findings on injury susceptibility during

"whiplash":

a. Neck muscle contraction may significantly lessen the likelihood of hard-tissue injury resulting from excessive lateral flexion. For stronger members of the population (e.g., males age 35-44) it may prevent such injury even for side-impact velocities of 30 mph. For weaker members of the population (e.g., females age 62-74), however, muscle strength is insufficient to prevent probable injury even for 10-mph impact.

b. Excessive lateral flexion injury is less likely when the neck musculature is voluntarily or involuntarily pre-tensed as a result of anticipation of impending impact.

c. Excessive lateral flexion injury is more likely in older members of the population than in younger because of both a more restricted voluntary range of motion and weaker neck muscles. Greater reflex time is a secondary disadvantage of older persons.

d. There is evidence for an increased likelihood of muscle tissue damage when the muscles are contracted, particularly at higher impact speeds. This type of injury is predicted to be most likely in weaker members of the population

This report has been compiled with the intent of providing researchers with data useful in computer modeling of crash impacts, design of improved dummies for sled tests, and development of safer passenger seats and head restraint systems, as well as in other practical applications in the field of automotive safety.

CHAPTER 1

INTRODUCTION, OBJECTIVES, AND BACKGROUND

A. Introduction

The term "whiplash" has commonly been applied to encompass the complex interactions which occur when the occupant of a vehicle is struck from the rear, resulting in cervical hyperextension-hyperflexion. It is also the case, however, that individuals incur "whiplash" injuries from forces resulting in lateral flexion of the neck such as would occur on side impact or rear impact with the head turned.

A previous study conducted for the Insurance Institute for Highway Safety entitled "Bioengineering Study of Basic Physical Measurements Related to Susceptibility to Cervical Hyperextension-Hyperflexion Injury," was designed to study the influence of such basic factors as sex, age, and stature on neck properties in the sagittal plane. This research (hereafter referred to as the "sagittal plane study") has resulted in a number of significant findings related to basic characteristics of the human neck in dorsal hyperextension and ventral hyperflexion motions. Data from the study have already been utilized in the design of the ATD-50 anthropomorphic dummy neck by General Motors Corporation, in seat designs by the Ford Motor Company, and in occupant protection and dummy standards now under development by the National Highway Traffic Safety Administration. Publications based on the

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The rights, welfare, and informed consent of the volunteer subjects who participated in this study were under guidelines established by the U.S. Department of Health, Education, and Welfare Policy on Protection of Human Subjects and accomplished under medical research design protocol standards approved by the Human Use Committee, School of Medicine, the University of Michigan.

sagittal plane study include a bibliography of whiplash and cervical kinematic measurement (Van Eck et al., 1973); a report on the mathematical modeling of relationships between physical characteristics of the neck and its susceptibility to injury (Robbins et al., 1974); a report on cervical range of motion and the dynamic responses and strength of cervical muscles (Foust et al., 1973); and a report of cervical sagittal plane dimensions (Katz et al., 1975). The study data undoubtedly will continue to be used in several future modeling studies and are useful for improving head and neck protection in vehicular accidents involving hyperextension-hyperflexion.

This initial study was significant in that a survey of the literature had revealed over 2,300 references related to the whiplash injury (Van Eck et al., 1973), yet no basic study had been conducted to measure physical characteristics and variations of the human neck in a representative U.S. population. While this work provided several new insights into whiplash injury mechanisms and established workable laboratory techniques, it was recognized that whiplash injuries often are produced from more complex motions than those measured. Rotation, extension, flexion, and lateral motions all may occur and greatly complicate the measurement, interpretation, and understanding of the injury mechanisms involved.

The present investigation, conducted from October, 1973, through December, 1974, was undertaken with the same representative population to investigate physical characteristics of the neck in lateral flexion and represents the culmination of nearly three years of intensive research into the basic mechanisms relating to susceptibility of individuals to "whiplash" injury. Much of the work involved solutions of complex problems in laboratory techniques, especially those relating to the use of three-dimensional photogrammetry in anthropometric and range-of-motion measurements. Although portions of this study will be independently reported in the literature, the objective of this report is to bring together in one place the bulk of the data so that it can more easily be used in future research and applications. The authors have attempted to compile this report in a format useful to other researchers and modelers and hope that the basic data provided will be of continuing use in the solution of applied problems. The following section outlines more specifically the research objectives of this study, while Section C of this chapter is intended to provide a brief summary of some of the recent literature relevant to "whiplash" injury.

B. Research Objectives

The specific objectives of this study include the following:

1) To determine comprehensive neck and torso anthropometry sufficient to:
    a) compare the subject pool to the general population and to previous sagittal study subject pools.
    b) locate major body masses.
    c) describe the seated occupant in three dimensions.
2) To measure variations in neck muscle strength in the lateral direction.
3) To determine variations in voluntary range of cervical motion in three dimensions, with emphasis on motions involving lateral flexion.
4) To determine variation in muscle response time to external

stimulus (i.e., head jerk) and to measure head acceleration (angular and linear) during reflex testing.

5) To determine the dynamic response of the human body in the lateral direction in car-to-car impacts using mathematical models of a crash victim and measured values of the above parameters, and to determine the sensitivity of these responses to changes in the parameters.

C. Background

Rear-end collisions commonly result in neck injury to the occupants of automobiles. Jackson (1966) estimated that 85% of neck injuries from automobile collisions are caused by rear-end impacts. This incidence was confirmed in a 1969 study, by States et al., of 13,800,000 vehicular collisions recorded in the U.S. during the year 1967. Of those, 78% were attributed to vehicle-to-vehicle impacts, and approximately 62% of these (6.5 million) were estimated to be due to rear-end collisions (Gurdjian and Thomas, 1970). Data prepared by the National Highway Traffic Safety Administration for 1968 indicated that rear-end collisions accounted for 23.5% of U.S. accidents and were responsible for 25.5% of the injuries and 4.5% of the fatalities (National Accident Summary Facts, n.d., Fig. 4). More recent data indicate that there were some 4,300,000 rear-end collisions during 1973 in the U.S. (National Safety Council, 1974, p. 47), which included 2,300 fatal impacts.

Resulting injuries to the neck are documented by an extensive clinical literature (Van Eck et al., 1973). The cervical hyperextension-hyperflexion ("whiplash") injury is characterized by symptoms referable to the neck, including cervical pain, tenderness, ligamental damage, muscle spasm, occipital headaches, retropharyngeal hematoma, dysphagia, and cervical spine fracture. Other injuries reported include subarachnoid and subdural hemorrhage, vertigo, EEG abnormalities, unconsciousness, and ill-defined mental changes. Acute or chronic symptoms of these lesions may appear immediately and persist for years, while in other cases symptoms attributed to the accident may not appear for a considerable time.

According to Jackson, the term "whiplash" was initially used in 1944 by Davis to describe the mechanism of neck injuries which occur in head-on collisions (i.e., an abrupt flexion of the neck followed by a recoil in extension). While "whiplash" may occur in this manner, the term is most commonly associated with the rear-end collision which results in the target vehicle occupants' necks being abruptly hyperextended, followed by rapid hyperflexion. It may also, however, refer to the lateral movement of the head resulting from side impact (called "side-lash" by Jackson) or rear impact with the occupant's head turned. The term "whiplash" has been widely misused in the literature associated with medical diagnosis, rather than as a descriptive term indicating a mechanism of injury (Braunstein et al., 1959; Knepper, 1963). The injury it is intended to describe results from hyperextension, hyperflexion or lateral flexion of the neck as the head rotates during collision impact.

To date the best treatment of the etiology of cervical injuries is by Jackson (1971). Injuries in head-on collisions causing forward hyperflexion of the neck followed by rearward hyperextension have been described as primarily placing traction on the anterior longitudinal ligament, the attachments of which may be stretched, torn, or avulsed at the margins of the vertebral bodies or at the annulus fibrosis of the intervertebral discs. Other injuries may include avulsion of fragments of the vertebral body, tears or ruptures of the annulus fibrosis, disc avulsion, tears of the longus colli and intertransverse muscle attachments, fractures of the spinous processes, laminae, articular facets, or the odontoid process, or avulsion of the capsular ligaments.

Similarly, whiplash injuries caused by rearward hyperextension of the head and neck followed by abrupt forward hyperflexion may involve tearing or stretching of the nuchal, the posterior longitudinal, the interlaminar, or the capsular ligaments, posterior facet dislocations (with or without cord injuries), vertebral body fractures, or other injuries. Otological aspects of "whiplash" injuries have been discussed by Pang (1971).

Less is known of the injuries occurring due to lateral flexion although Roaf (1963) has suggested that tearing of the intertransverse ligaments, fracture of transverse processes, and lesions of the brachial plexus and spinal cord may be indications that this was the mechanism of injury. If the head is also rotated at the same time, a broad variety of injuries may result.

While several studies have been concerned with the occurrence of cerebral injury induced by whiplash, controversy over the mechanisms responsible continues. There is now a divergence of opinion concerning the respective roles of translational and rotational acceleration in the concussive mechanism of whiplash, and there is growing evidence of correlations between injury and such factors as head-to-restraint distance, rotational acceleration effects (Portnoy et al., 1971), mass of the head, location of the center of gravity of the head, and orientation of the head at initiation of impact.

Studies of concussion have often resulted as an outgrowth of "whiplash" experiments. Martinez (1965), for example, reported brain injury associated with whiplash in rabbits, while Mahone et al. (1969) and Ommaya et al. (1966, 1970) have utilized sub-human primates. A detailed discussion of the relationships reported in the literature may be found in Snyder (1970). A joint Army-Navy-Wayne State University experimental program of 236 dynamic human exposures to $-G_x$ impact acceleration in 1967-1969, and continued by the Navy at Michoud/NASA, resulted in independent measurement of the displacement of the head relative to the neck in the plane of rotation through electronic and photographic techniques (Ewing et al., 1968; Ewing et al., 1969; Ewing and Thomas, 1971; 1972; 1973), as well as a number of other parameters critical to protection against cervical injury. Clark et al. (1971) determined head linear and angular accelerations during human exposure to abrupt linear deceleration while restrained by an air bag plus lap belt restraint. In 14 tests with adult male volunteers at peak sled velocities to 26.2 ft./sec. and 7.8 to 10G, results indicated that peak head angular accelerations and linear resultants may have less traumatic consequences than the degree of head-neck hyperextension. In simulated rear-end collisions in crashes with 53 human cadavers, Clemens and Burow (1972) noted that the most common and serious injury was to the spine at the level of the sixth cervical vertebra. Unembalmed cadavers were also tested by Gadd, Nahum, and Culver (1971) who found ligamentous injury at a similar degree of hyperextension, but approximately 15% greater moment of resistance was noted during the time in the loading cycle when angular velocity was greatest.

The incidence and severity of "whiplash" injury apparently is not always related to the magnitude of the change in velocity of the impacted vehicle, since many other factors, such as effect of any head restraint, head-torso position and orientation to the force at the instant of impact, etc., influence the results. For example, one motorist who had been rear-ended by another received a liability verdict for resulting injuries of $452,000 in a 1973 case, although total damage to the injured person's vehicle was only reported to be $28 (USAA, 1973). On the other hand, the principal author driving on a free-way at 55 mph, was rear-ended in a 1965 collision by a vehicle being chased by the police and clocked at 90 mph at impact. Although both cars were demolished, the author was uninjured by this 45 mph change-in-velocity impact.

Directly related to a better understanding of the mechanisms involved in and factors causing various aspects of whiplash injury is a need to understand the role that the basic properties of the human neck (such as anthropometry, range of motion, strength, and reflex time) play in preventing whiplash injury on impact. Prior to the sagittal plane study, however, variations in these physical properties of the neck with age, sex, and stature and consequent changes in susceptibility to whiplash injury were virtually unknown, although recent statistics indicate that such factors may have an important effect on injury susceptibility.

For example, recent clinical examinations of victims of whiplash injury indicated a significant preponderance of whiplash symptoms among females. Kihlberg (1969) reported a substantially greater frequency among women "up to twice as high as among men". Gurdjian has reported

207 cases of hyperextension-hyperflexion injuries seen in a three-year period, of which 129 were female and 75 were male (Gurdjian, Cheng, and Thomas, 1970). Field investigations appear to confirm this assessment (O'Neill et al., 1972). Schutt and Dohan (1968) have found disabling neck injuries to women "common" in accidents in metropolitan areas, ranging from 6.7 to 14.5/1,000/year, half occurring from rear-end collisions.

Along with these statistics it is interesting to note that Sinelnikoff and Grisorwitsch (1931) found that females exceed males in range of motion of all joints except the knee, often to a significant extent. Age-related diseases such as arthritis have been found to result in a marked decrease in joint mobility after age 45 (Smith, 1959). A decrease of about 21% in "normal" flexion-extension motions of subjects aged 15 to 74 was reported by Ferlic (1962). He also found a decrease of lateral bending motions of 35% and a decrease in rotation with age of about 20% although he took no x-rays of these subjects. However, Lysell (1969), using 28 cadaver specimens, has reported that degenerative changes "had no effect on the range of motion in any planes or in any interspaces."

Cervical joint motion has been studied by various techniques, including multi-exposure films (Dempster, 1955), cyclograms (Drillis, 1959), and photographic techniques devised by Taylor and Blaschke (1951) and Eberhart and Inman (1951). Bhalla and Simmons (1969) have devised a simple apparatus to determine range of motion radiographically, and, from studies on 20 student nurses between ages 19-23, have postulated that in flexion the injury would most likely occur at C6-C7 or C7-T1; while in extension, injury would occur most often at C2-C3, C3-C4, or

C5-C6. Mertz and Patrick (1971) have reported that the best indicator of the degree of severity of neck flexion is the equivalent moment of the neck and chin contact forces taken with respect to the occipital condyles.

The "normal" range of neck flexion has been studied in male subjects by Glanville and Kreezer (1937), Defibaugh (1964), and more recently summarized by Lysell (1969). However, difficulties reported have involved reproducibility, intra-individual range or variation, and lack of adequate landmark standards. As a result of the first major attempt to obtain linkage data on the mobility of the human torso, including the neck, the authors devised techniques which have provided an improved basis for study of neck motion (Snyder, Chaffin, and Schultz, 1971). Hadden (1973) has considered head injury from an epidemiological point of view and has proposed useful basic principles and considerations which should be employed. The mechanics of lateral bending were studied in 1972 by Veleanu and Klepp, using macerated vertebrae. Lange (1971) has also used human cadavers subjected to severe test-sled decelerations to determine gross injuries to the cervical vertebrae caused by torque, axial, and shear forces. Mertz and Patrick (1967) simulated the kinematics of rear-end collisions using anthropometric dummies, and reported that neck torque rather than neck shear or axial forces is the major factor in producing cervical trauma.

In an attempt to protect the autmobile occupant subjected to rear-end impacts, Federal Motor Vehicle Safety Standard No. 202 (1968) required all passenger cars manufactured after 31 December 1968, for sale in the U.S., to be equipped with head restraints at each outboard front seating position. Up to that time, experimental data were limited (Severy et al., 1968; Mertz and Patrick, 1967).

States et al. (1969) have reported 6 cases of injury incurred by occupants while utilizing head-restraints, and hypothesized that two mechanisms, rebound and too low a head-restraint adjustment for the seated height of the individual, were responsible. In one case it was found that a head restraint adjusted in the lowermost position (25"), protecting occupants who are 5 feet six inches tall or shorter, failed to prevent whiplash to the 6-foot driver as he ramped up the seat back and his head hyperextended over the top. A recent study by O'Neill, Hadden, Kelley, and Sorenson (1972) found that 80% of all adjustable restraints surveyed were not properly positioned, and concluded that "head restraints are the first damage-reduction measure to be applied to the whiplash injury problem"(p.405). Garrett and Morris (1972) also evaluated head restraint performance and reported approximately 73% of the adjustable head restraints examined were in the lowest position, indicating that proper usage for protection may present the same problem as getting motorists to use active seat restraints. They also found that cervical injury was lower when the amount of seat back rotation was large. Henderson (1972) evaluated head restraint in Australian vehicles and noted that to be effective seat belts also should be worn to prevent the body from sliding upwards and snapping the head over the back of the "restraint."

The effect of seat design on cervical injury has been examined by Berton (1968) who analyzed the effect of seat back height, seat back horizontal distance, rotation, and collision speed. Severy, Brenko and Baird (1968) also studied the effect of backrest and head restraint design. These tests sponsored by Ford Motor Company and the Public

Health Service, used a series of collision experiments to study various seat designs under crash conditions. An unpublished study by Hammond (1968) at Ford Motor Company estimated cervicale location, referenced to H-point for drivers sitting in an automotive type seat, as 19.31 inches above H-point for males and 19.27 inches for a combined male-female population. This estimate was located at the intersection of the SAE torso line with a 25° back angle.

Protection of the occupant from rear-impact collision loads to 80 km/hr through improved design has been reported in experimental tests by Ford Motor Company Limited, England (Burlard, 1974) by improving structure, stiffening the seat, and adding a foam padded roll of sheet metal for head restraint.

Metz and Ruhl (1972) found that under certain conditions crash helmets worn by racing drivers can actually contribute to whiplash injury rather than reduce it.

A recent patent application (Ommaya et al., 1973) would employ an inflatable cervical collar, worn about the neck of the vehicle occupant and inflated with compressed gas during a rear-end collision to prevent a "whiplash-like head or neck injury." Thurston and Fay (1974) tested an inflatable air bag collar to limit head motion, using a single-degree-of-freedom mechanical system.

Mathematical models representing the neck and head motion of an occupant during rear impacts have been developed by Martinez and Garcia (1968), Higuchi, Morisawa, and Sato (1970), Furusho, Yokoya, Nishino, and Fujiki (1971), and Li, Advani, and Lee (1971). Melvin and McElhaney (1972) have considered improving occupant protection in severe rear-end collisions from the standpoint of high performance seat structures and both fixed and deployable head restraints, based upon two-dimensional computer simulations. This resulted in devlopment of prototype systems which were dynamically tested. Bowman and Robbins (1972) reported a parameter study involving several analytical vehicle occupant models for side, oblique, and rear impact situations, and having concluded that besides being extensible and have at least two joints, 3-D neck representations should account for coupling between the forces resisting rotational motions which can occur between the head and torso.

The HSRI (MVMA) Two-Dimensional Crash Victim Simulator (Robbins, Bennett, and Roberts, 1973) was also utilized to show how the basic physical measurements obtained in the earlier portion of this study (cervical motion in the sagittal plane) may relate to susceptibility to injury in a rear-end collision (Robbins, Snyder, Chaffin, and Foust, 1974). Among conclusions reported were that the geometric configuration of a seat back and headrest has a major influence on occupant dynamics, that rubber neck structures found in some crash test dummies may be too stiff and springy to represent human response, and that males and females can influence their dynamic response in a 15G rear-end collision to different degrees.

In the present study the effect of muscle reflex time with muscle tension buildup (surprise collision) and varying degrees of muscle pretension on occupant response to side impacts of 10 and 30 mph have been investigated using the MVMA 2-D model. It is concluded that neck muscle contraction may significantly lessen the likelihood of hard-tissue injury resulting from excessive lateral flexion, and that the lesser muscular strength of female and elderly crash victims indicates greater susceptibility to neck injury for these groups.

CHAPTER 2

METHODS AND PROCEDURES

This Chapter includes a description of the protocol and methodology used to acquire subjects and generate data for the study. The techniques used to recruit and medically screen volunteer subjects are described, as are the methods used to conduct the anthropometric, range of motion, muscle reflex, and muscle strength tests. Data reduction and analysis methods are discussed in this Chapter; results are presented in Chapter 3. Throughout the remainder of the report, the phrase "sagittal plane study" refers to the "Bioengineering Study of Basic Physical Measurements Related to Susceptibility to Cervical Hyperextension-Hyperflexion Injury," which was conducted for the Insurance Institute for Highway Safety during 1972 and 1973. Similarly, "lateral motion study" refers to "Basic Biomechanical Properties of the Human Neck Related to Lateral Hyperflexion Injury," for which this is the final report.

A. Subject Acquisition and Screening

1. Subject Pool. The basic experimental design for this study called for a subject pool of 96 persons, balanced for sex, age, and stature. This was the same experimental design concept as used in the sagittal plane study. However, the results of the sagittal plane study indicated that the neck characteristics of interest were relatively insensitive to stature while being very sensitive to sex and age differences. This determination, together with the smaller total subject pool desired (96 instead of 180 subjects), led to a decision to eliminate stature as a major variable. Sex and age are therefore

the major variables in this study, while stature is considered a minor variable within each sex and age group. The final statistical design chosen for the subject pool was then 2 x 3 factorial, with categorization by sex and by the same three age groups as were designated in the sagittal plane study (18-24 years, 35-44, and 62-74). Each of the six subject categories was intended to contain 16 subjects, for a total of 96 in the study. Stature is accounted for within each category by selecting three subjects each of short and tall stature and the remaining ten of average stature. ("Short" was defined as the 1-20th percentiles of the appropriate sex and age category, according to the U.S. Public Health Survey (1962), "average" was selected to include statures in the 40-60th percentiles, and "tall" included the 80-99th percentiles.) This method of stature selection was intended to bias the results toward the 50th percentile groups without ignoring the extremes of the population. Thus, the subject sample population was selected to be representative of the entire U.S. adult population with respect to the major variables.

2. Subject Recruitment. Since this study was intended to supplement and expand the results of the sagittal plane study, it was desirable to conduct the new tests with as many subjects as possible from the previous study. A letter which summarized the sagittal plane study results and outlined the intent of the lateral motion study was sent to each of the 180 participants (See Figure 2.1). Included was a tear-off form which was to be returned if the subject was interested in participating in the new program. The response was very good: eighty-two subjects returned the form. Of those, 67 fit the subject categories in the desired proportions of short, average, and tall

HIGHWAY SAFETY RESEARCH INSTITUTE
Institute of Science and Technology
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THE UNIVERSITY OF MICHIGAN

May 17, 1974

Dear Subject:

Last year the Biomedical Department of Highway Safety Research Institute, funded by the Insurance Institute for Highway Safety, completed an extensive scientific examination of cervical hyperextension-hyperflexion (whiplash involving forward and backward motion of the head), a study in which you participated. An abstract of a paper written on the results of this study, "Cervical Range of Motion and Dynamic Response and Strength of Cervical Muscles," Foust, D. R., *et al.*, is enclosed. Reprints of this article may be obtained by written request to:

Dr. R. G. Snyder, Head
Biomedical Department
Highway Safety Research Institute
Baxter at Huron Parkway
Ann Arbor, MI 48105

Because of our significant findings, the Insurance Institute for Highway Safety has agreed to sponsor an extension so that we are able to continue our efforts with a study involving lateral cervical hyperflexion (whiplash involving side to side motion of the head). This study will include anthropometry (body measuring), and photogrammetry, along with strength and reflex time tests similar to those in the original study.

The significance of our present study results would be greatly enhanced by obtaining further measurements from the same people who were tested in our original study. Therefore, we are inviting you to apply for participation by simply filling in the form at the bottom of this letter and returning it to us in the enclosed, self-addressed envelope. As in the past, subjects will be reimbursed for their participation.

If you have any questions, please do not hesitate to call Ann Russ Desautels or Tommy Abdelnour at 313/763-3582.

Sincerely,

Ann R. Desautels

Ann Russ Desautels
Subject Coordinator

- - - - - - - - - - cut along dotted line - - - - - - - - - -

NAME ______________________________ Address ______________________________
Last First Middle Street City State Zip

Phone ______________________________ Birthdate ____________________ Weight ______
Area code Home Work Mo Day Yr Lbs.

Figure 2.1 Letter to participants in sagittal plane study.

stature. Those 67 constituted 70% of the 96 subjects required for the study. All of the needed subjects of short and tall stature were recruited in this manner, as were 31 of the 60 people of average size.

In several short and tall stature groups, more returning subjects were available than were needed in the category. In those cases, the combination of three subjects was chosen who most closely fit (by mean and standard deviation) the stature results of the previous study. This within-category matching produced a group of sixteen subjects which statistically matched the statures of the thirty subjects previously measured in a comparable sex/age group.

The canvass of previous subjects produced 67 subjects, making it necessary to locate only 29 new participants. Of these, fifteen were in the young age category, since many previous participants were university students who had subsequently graduated and moved away. The majority of the new subjects required were recruited from advertisements in the campus and local general circulation newspapers; a few were obtained on recommendations of friends.

3. Screening Procedures and Final Approval. Two methods were used for health screening and approval for participation in the study. Returning subjects were questioned as to their health history since participating in the sagittal plane study. If there was no change and no indication of injury in the intervening period, they were allowed to participate in the lateral-motion study. No additional neck x-rays were obtained from returning subjects.

Newly recruited subjects were screened in a manner similar to that used for the sagittal plane study. Each potential subject completed a general health questionnaire (Figure 2.2). This was reviewed and

Date______________ HEALTH QUESTIONNAIRE (Please Print) Subject No.______________

NAME________________________________ PHONE(S):______________

Last First Middle ______________

ADDRESS____

Street City State Zip

Soc. Sec. No.______________ Birthdate______________ Age______

Height__________ Weight__________

DIRECTIONS: Answer all questions. If you are uncertain as to how to best answer a question please circle Yes or No and explain further either at space provided after question or at the end of the questionnaire with the letter and number marked.

SECTION I:

1. Do you have a driver's license?........................Yes No
   a. Approximately how many miles do you drive a year?__________
2. Has your eyesight changed recently?....................Yes No
3. Do you hear ringing or buzzing in your ears?...........Yes No
4. Do you have pains in your chest?.......................Yes No
   a. If yes, explain______________________________
5. Do you get short of breath long before anyone else?....Yes No
   a. If yes, explain______________________________
6. Have you lost more than 10 pounds in the past 3 months.Yes No
7. Do you have severe pains in your abdomen (stomach)?....Yes No
8. Did a doctor ever say you had diabetes (sugar in the blood and urine)?.....................................Yes No
9. Does severe rheumatism (or arthritis) interfere with your work?..Yes No
10. Are you now under a doctor's care?.....................Yes No
    a. If yes, doctor's name and address______________

SECTION II:

1. Do you need glasses for reading or other close work?...Yes No
2. Do you need glasses for seeing things at a distance?...Yes No
3. Has your eyesight ever blacked out completely?.........Yes No
4. Do you ever see things double or blurred?..............Yes No
5. Do your eyes continually blink or water?...............Yes No
6. Do you ever have severe pains in or behind your eyes?..Yes No
7. Do you often see spots before your eyes?...............Yes No
8. Are your eyes often red or inflamed?...................Yes No
9. Are you hard of hearing?...............................Yes No
10. Have you had frequent severe ear aches?................Yes No
11. Have you ever had a running ear?.......................Yes No

Figure 2.2 Health Survey Questionnaire.

SECTION III:

1. Have you ever been hoarse for more than a month?.......Yes No
2. Have you ever had frequent or severe nose bleeds?......Yes No
3. Have you had any x-rays, especially a chest x-ray?.....Yes No
4. Did your chest x-ray show anything in your chest?......Yes No
5. Were you ever in an automobile accident where you might have suffered "whiplash" or neck injury?...............Yes No

SECTION IV:

1. Has a doctor ever said your blood pressure was too high or too low?...Yes No
2. Does your heart often beat very rapidly?...............Yes No
   a. If yes, explain ____________________
3. Do you ever have difficulty in getting your breath?....Yes No

SECTION V:

1. Do you have any difficulty in swallowing?..............Yes No
2. Are you often sick to your stomach with vomiting?......Yes No
3. Do you often have indigestion?.........................Yes No
   a. If yes, explain ____________________

SECTION VI:

1. Have your joints ever been painfully swollen?..........Yes No
   a. If yes, explain ____________________
2. Do your muscles and joints always feel stiff?..........Yes No
   a. If yes, explain ____________________
3. Do you usually have severe pains in the arms or legs?..Yes No
   a. If yes, explain ____________________
4. Are you crippled with severe rheumatism (or arthritis)?Yes No
   a. If yes, explain ____________________
5. Does rheumatism run in your family?...................Yes No
   a. If yes, explain ____________________
6. Do you suffer from weak or painful feet?...............Yes No
7. Do you have pains in the back or neck that make it hard for you to keep up with your daily activities?.........Yes No
8. Are you troubled by a serious bodily disability or deformity?...Yes No
   a. If yes, explain ____________________

SECTION VII:

1. Do you have frequent severe headaches?.................Yes No
2. Do you often have spells of severe dizziness?..........Yes No
3. Have you fainted more than twice in your life?.........Yes No
   a. If yes, explain ____________________
4. Are you ever aware of numbness or tingling in any part of your body?..Yes No
5. Was any part of your body ever paralyzed?..............Yes No
   a. If yes, explain ____________________

Figure 2.2 Continued.

6. Were you ever knocked unconscious?..................Yes No

a. If yes, explain ______________________

7. Have you ever noticed a twitching of any part of your body? (other than eyes)............................Yes No

a. If yes, explain ______________________

8. Did you ever have a convulsion (epilepsy)?...........Yes No

9. Has anyone in your family ever had convulsions (epilepsy)?..Yes No

SECTION VIII:

1. Are you definitely overweight?.......................Yes No

2. Are you definitely underweight?......................Yes No

3. Has there been any recent change in your weight?......Yes No

4. Have you ever had a serious operation?...............Yes No

a. If yes, explain ______________________

5. Have you ever had a serious injury?..................Yes No

a. If yes, explain ______________________

6. Do you often have small accidents or injuries?........Yes No

a. If yes, explain ______________________

SECTION IX:

1. Are you considered a nervous person?.................Yes No

Additional comments: (Please include dates, symptoms, frequency of occurrence, and any other relevant data.)

____

____

____

____

____

____

____

Note: This questionnaire modified from the Cornell Medical Index for the R.I.W.U. multiphasic testing, June 1951.

Figure 2.2 Continued.

approved, if acceptable, by Dr. Janet Baum, the radiologist consultant to the study. The subject was then scheduled for a series of radiographs of the neck which were taken in the radiology laboratory at HSRI (Figure 2.3). Three views were obtained for each new subject --a lateral "dropped shoulders" view in neutral position, an anterior-posterior view in neutral position, and an anterior-posterior view with the neck in right lateral bend position. These two latter views for one subject are shown in Figure 2.4. The x-rays were then submitted to Dr. Baum for review. Upon her approval, the new subjects were allowed to participate in the remainder of the test program.

Each subject, new or returning, was thoroughly briefed on the nature of the tests being conducted and the amount of physical activity required. If the subject agreed to participate, he or she was asked to sign a subject consent form (Figure 2.5). At this point, the subject was considered to be part of the final subject pool.

All subjects were scheduled for testing in two sessions. This required different testing sequences, since it was necessary for all medical screening to be completed before new subjects could perform the relatively strenuous range-of-motion, reflex time, and strength tests.

The following test sequences were used:

Returning Subjects	New Subjects
Session 1:	Session 1:
Anthropometry (Traditional)	X-rays
Anthropometry (from Photogrammetry)	Anthropometry (Traditional)
Range-of-Motion (from Photogrammetry)	

Figure 2.3 Lateral Bend X-ray being obtained from potential subject. X-rays were taken in HSRI Radiology Laboratory.

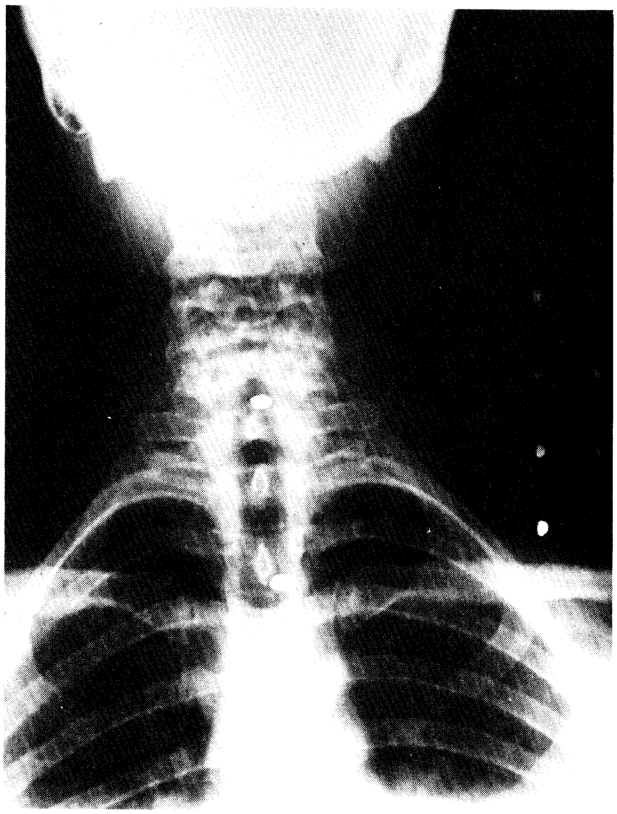


Figure 2-4a. Neutral Position View.

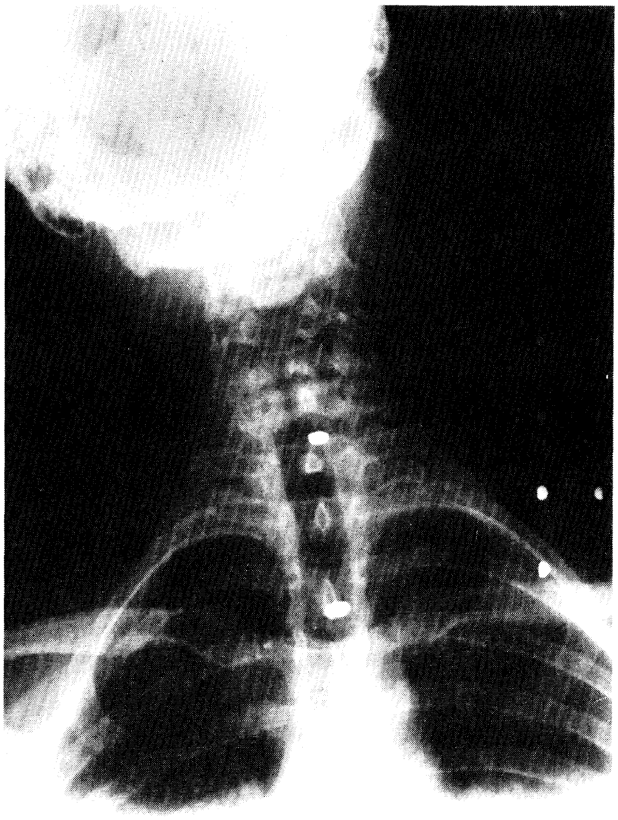


Figure 2-4b. Right Lateral Bend Position.

Figure 2-4. Anterior-Posterior radiographs of potential subject. Note: the difficulty in delineating individual vertebrae in the cervical spine; the lead markers at C-7, suprasternale, and the two tragions; and the pendulum marker which indicates verticality.

HIGHWAY SAFETY RESEARCH INSTITUTE
Institute of Science and Technology
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105

THE UNIVERSITY OF MICHIGAN

Subject #________

Date __________

SUBJECT CONSENT FORM

I, the undersigned, understand that the purpose of this study is to determine basic information on the human neck necessary for improved protection of the occupant in automotive accidents. Specific tests in which I will be asked to be a subject include anthropometric measurements, neck muscle strength, voluntary range of motion, and variation in muscle response time. I acknowledge that I have received a complete briefing of these tests and am satisfied that I understand what is involved.

I have completed the health questionnaire, and am aware that my participation will be subject to medical screening both as to any history or findings which might make it inadvisable for me to continue. I realize that some discomfort or muscle strains could result from my participation, although the experimental procedures and apparatus have been designed to minimize these hazards.

I also understand that I will be allowed, at any time, to stop for rest or to discontinue my participation in this study without prejudice or change in the rate of my pay.

I further acknowledge that all the data are confidential and I agree to allow publication of any or all of the data collected if presented in a coded form not identifying me.

____
Signature of Subject

____
Signature of Witness

Figure 2.5 Subject Consent Form.

Session 2:	Session 2:
Reflex Time	Reflex Time
Strength	Strength
	Anthropometry (from Photogrammetry)
	Range-of-Motion (from Photogrammetry)

B. Anthropometry

As procedures for the orthogonal photogrammetry system (described in the next section) were being formulated, it was suggested that significant new anthropometric data for a seated person could become available by using that technique. Consequently, it was decided to modify and expand the anthropometry in this project to include measurements obtained by both traditional and photogrammetric methods. The age and sex stratification of the subject pool, the numbers of persons involved, and the experienced nature of the subject group (most had participated in the previous study and were basically familiar with anthropometry procedures) prompted us to obtain a completely new set of measurements from each of the subjects.

1. Objectives. Four objectives were identified for the anthropometry portion of the study:

a. Recheck body dimensional data from previously measured subjects. Certain bony-landmark measurements, such as stature, erect sitting height, and biacromial breadth, were used as a check of measurement-method repeatability with the previous study. Others, such as weight, circumferences, and skinfolds, were used to assess changes in soft-tissue dimensions.

b. Obtain population-comparison data. Certain of the anthropometry data were used to compare this study population with both the sagittal plane study results and the U.S. population (see Chapter 3, Section A). The same selection criteria for age and stature as were used in the sagittal plane study were used for this study.

c. Obtain and recheck head and neck dimensional data. Some measures were repeated for comparison with previous results (e.g., bitragion diameter, sagittal arc length, head breadth). Certain others were added (e.g., facial height, glabella arc, menton arc) to obtain sufficient data to describe the shape and major landmarks of the head in three dimensions.

d. Obtain data to describe the seated person in three dimensions. Three-dimensional data on the mobility of the torso, neck and lower back were available from a limited number of young male subjects (Snyder, Chaffin, and Schutz, 1972). Also, the automotive industry and the SAE had attempted to establish eye locations in relation to a set surface (Meldrum, 1965; SAE J9Y1C, 1972). However, prior to this study, there was no cohesive set of measurements that could be used in biomechanical models to establish the size and position in a seat of a simulated crash victim. A major objective of this study, then, was to use a combination of the photogrammetry technique, computerized data reduction, and traditional anthropometry to obtain a unique set of dimensions. These data were to be sufficient to define body segment size and describe the dimensional relationships of the head, neck, torso, limbs and, to a limited degree, the pelvis, in a simulated automotive seated position. This information was intended to be directly applicable to biomechanical models and to include, for the first time, sex and age variations.

2. The Measurements. The anthropometry data collected during this study consisted of a total of 84 separate measurements per subject. Of these, sixty were taken by traditional means, using a variety of hand-held instruments. The remaining 24 were obtained by computerized data analysis of photographs, the details of which are illustrated and discussed in Appendices D and E.

The 84 measurements, grouped into six general categories, are listed in Figure 2.6. Detailed definitions, both written and illustrated, have been compiled for all of the measures and are included as Appendix A to this report. These are included so that interested parties may use the data appropriately and compare it with the results of other studies.

The general body measurements (Group I) are the three which are used to compare populations -- weight, erect stature, and erect sitting height. They were obtained using standard anthropometric techniques.

A set of eleven head measurements was obtained (Group II). These may be used to reconstruct the basic three-dimensional contours of the head, using the landmarks at glabella, tragion, inion, and menton as primary locators. Standard anthropometry instruments and techniques were used.

The dimensional characteristics of the neck are described with five measures (Group III). Two breadths and two circumferences depict the basically cylindrical shape of the neck. The lateral neck breadth and superior neck circumference measurements are illustrated in Figures 2.7a and 2.7b, respectively. The fifth measure was contrived

ANTHROPOMETRIC MEASUREMENTS

I. GENERAL BODY MEASUREMENTS

1. Weight
2. Stature
3. Erect Sitting Height

II. HEAD MEASUREMENTS

4. Head Circumference
5. Bennett Ellipse Circumference
6. Bitragion Diameter
7. Head Breadth
8. Head Length
9. Sagittal Arc Length
10. Coronal Arc Length
11. Bitragion - Glabella Arc Length
12. Bitragion - Menton Arc Length
13. Bitragion - Inion Arc Length
14. Facial Height

III. NECK MEASUREMENTS

15. Lateral Neck Breadth
16. Anterior - Posterior Neck Breadth
17. Superior Neck Circumference
18. Inferior Neck Circumference
19. Posterior Neck Length

IV. MEASUREMENTS TO DETERMINE SIZE AND LOCATION OF MAJOR BODY MASSES

20. Biacromial Breadth
21. Shoulder Breadth (Bideltoid)
22. Chest Height
23. Chest Breadth
24. Chest Circumference
25. Waist Height
26. Waist Breadth
27. Waist Circumference
28. Hip Height
29. Hip Breadth (Standing Erect)
30. Hip Circumference
31. Acromion - Radiale Length
32. Upper Arm Circumference (at Axilla)
33. Upper Arm Circumference (above Elbow)
34. Biceps Flexed Circumference
35. Radiale - Stylion Length
36. Forearm Circumference

Figure 2-6. List of Anthropometric Measurements

37. Wrist Circumference
38. Hand Length
39. Trochanter - Femoral Condyle Length
40. Upper Thigh Circumference
41. Lower Thigh Circumference
42. Fibula Length
43. Fibula Height
44. Calf Circumference
45. Ankle Circumference
46. Foot Length
47. Ball of Foot Breadth

V. MEASUREMENTS RELATED TO SOMATOTYPES

48. Humeral Biepicondylar Diameter
49. Femoral Biepicondylar Diameter
50. Triceps Skinfold
51. Subscapular Skinfold
52. Suprailiac Skinfold

VI. BODY ELEMENT LOCATIONS FOR THE SEATED OCCUPANT

53. Normal Sitting Height (Relative to Seat Reference Point)
54. Tragion Height (Rel SRP)
55. Tragion Depth (Rel SRP)
56. Glabella Height (Rel SRP)
57. Glabella Depth (Rel SRP)
58. Eye Ellipse Point Height (Rel SRP)
59. Eye Ellipse Point Depth (Rel SRP)
60. Eye Ellipse Point Width (Rel Glabella)
61. Cervicale Height (Rel SRP)
62. Cervicale Depth (Rel SRP)
63. Suprasternale Height (Rel SRP)
64. Suprasternale Depth (Rel SRP)
65. Shoulder Height (Rel SRP)
66. Shoulder Depth (Rel SRP)
67. Shoulder Breadth
68. Anterior Superior Iliac Spine Height (Rel SRP)
69. Anterior Superior Iliac Spine Depth (Rel SRP)
70. Bispinous Breadth
71. Trochanterion Height (Rel SRP)
72. Trochanterion Depth (Rel SRP)
73. Bitrochanterion Diameter
74. Hip Breadth (Seated)
75. Infraorbitale Height (Rel Tragion)
76. Infraorbitale Depth (Rel Tragion)
77. Tragion Height (Rel Cervicale)
78. Tragion Depth (Rel Cervicale)
79. Glabella Height (Rel Tragion)
80. Glabella Depth (Rel Tragion)

Figure 2-6 Continued

81. Eye Ellipse Point Height (Rel Tragion)
82. Eye Ellipse Point Depth (Rel Tragion)
83. Ectocanthus Height (Rel Tragion)
84. Ectocanthus Depth (Rel Tragion)

Figure 2-6 Continued

2.7a Lateral Neck Breadth.

2.7b Superior Neck Circumference.

Figure 2.7c Posterior Neck Length (Cervicale to Inion).

Figure 2.7 Representative neck measurements.

for this study. Called posterior neck length, it was taken as shown in Figure 2.7c, with the head and neck fully flexed. It was obtained to test the hypothesis that neck length may be correlated with neck range-of-motion results. If so, it would provide a convenient method for estimating the potential range of motion of a person's neck.

A group of 28 measurements (Group IV) was obtained to describe, in dimensions useful in biomechanical models, the major body masses of the torso and limbs. The technique used was to define, with three measurements, the size and extent of the various body regions. The regions defined include chest, waist, hips, upper and lower arms, hands, upper and lower legs, and feet. Torso segments were described by a breadth and circumference and located by reporting the height (with subject erect) at which the breadth and circumference were measured. Limb segments are described by proximal and distal circumferences and a segment length. The chest measurement sequence is depicted in Figure 2.8. If an elliptical horizontal cross-section of the body is assumed for a biomechanical model, the chest circumference becomes the chest mass ellipse, the chest width becomes the long axis of the ellipse, and the chest height specifies where to locate the chest mass element on the body.

Five measurements of a specialized nature (Group V) were taken so that body build could be estimated by the Heath-Carter Somatotype technique (Heath and Carter, 1967).

Finally, 32 measurements (Group VI) were obtained with the objective of describing the location of a number of important body landmarks in the relaxed seated position. A combination of traditional and photogrammetric techniques were used to obtain these measurements.

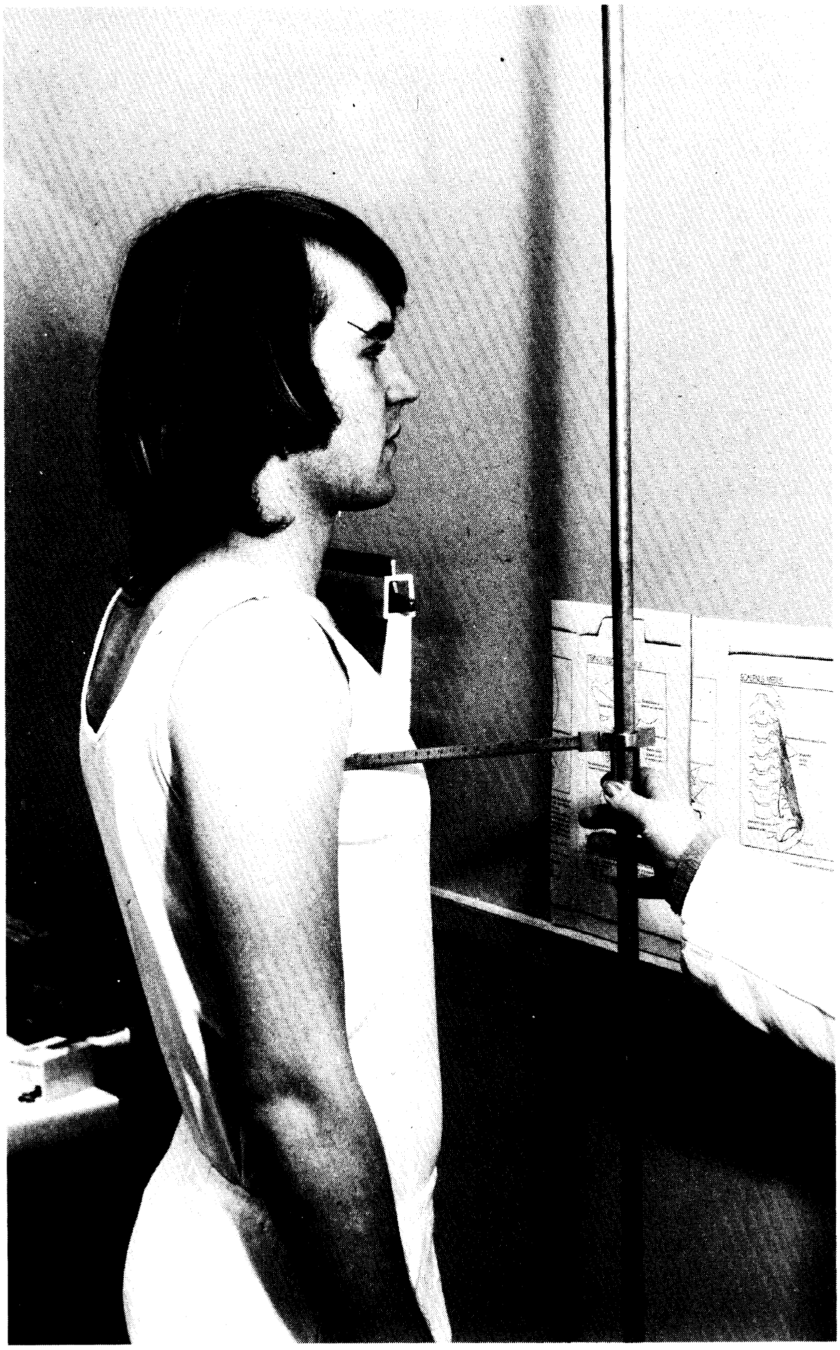


Figure 2.8a Chest Height measurement. A wall-mounted anthropometer is used.

Figure 2.8 Method of specifying location and size of major body masses. The chest measurement sequence is illustrated, and the same three measures were repeated at the waist and hips.

Figure 2.8b Chest Breadth measurement.

Figure 2.8c Chest Circumference.

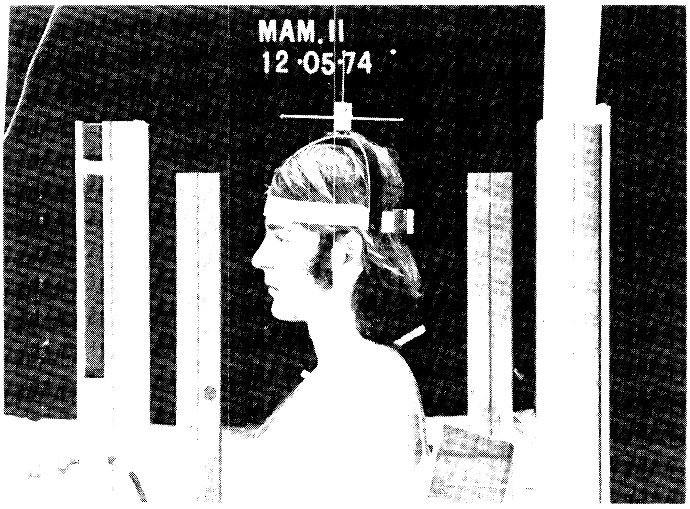
Figure 2.8 Continued.

A very careful procedure was followed to assure that the seated-position data remained coherent; that is, that the subject did not move any of the body segments of interest while measurements were being taken. The subject was positioned on an unpadded simulated auto seat (seat pan angle 6° below horizontal, seat back 103° to seat pan) with the buttocks firmly against the seat back, the subject's back resting comfortably against the seat back, and the mid-sagittal plane of the subject in the middle of the seat. The subject was instructed not to move the pelvic area or legs. Measurement reference marks and high-contrast markers were then placed at various locations on the head and torso. Pelvic measurements were then taken immediately, using hand-held instruments since the pelvis was outside the field-of-view of the photogrammetry cameras. Specially modified instruments were then used to place the subject's head in the Frankfort Plane neutral position, after which the normal sitting height dimension was taken. Immediately thereafter, the anthropometry photograph was taken with the three orthogonally-placed cameras. Figure 2.9 is an example of the photographs obtained from a subject in this position. Analysis of the photographs provided 24 measures, all of which were obtained with the subject in a consistently immobile position.

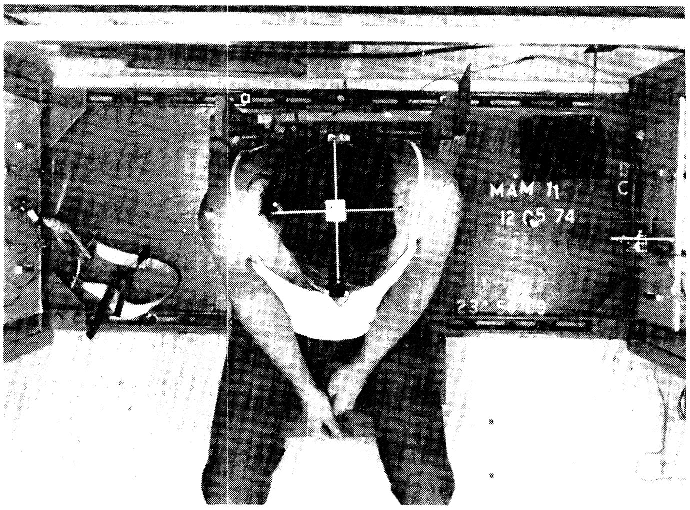
The traditional anthropometry measurements were recorded on a prepared form and then keypunched for statistical analysis using the University of Michigan's Statistical Research Laboratory MIDAS programs. The computer output from the photographic analysis was similarly keypunched for statistical analysis.

It should be noted from Figure 2.6 that many of the height and depth dimensions for the seated person were calculated with respect to

X-camera view.



Y-camera view.



Z-camera view.

Figure 2.9 The Anthropometry Neutral position. The subject is seated in a simulated auto seat, with his head in the Frankfort Plane neutral position. Reference marks on the face and upper torso are analyzed by computer to provide 24 anthropometric measures which locate the body landmarks with respect to the seat and each other.

an inertial coordinate system with origin at a Seat Reference Point (SRP). This is a consistent external reference point, defined as the point of intersection of the seat back, seat pan, and center of the seat. All head, torso, and pelvis landmarks are reported relative to the Seat Reference Point. In addition, several head and eye dimensions are located with respect to other points on the body. Finally, in order to make the seated-position data as generally useful as possible, Appendix B includes the X, Y, and Z locations of each of the body landmarks relative to the SRP.

As stated above, one of the objectives of the anthropometry is the direct applicability of the data to three-dimensional modeling of the human body in the seated position. To test the completeness of the dimensions, the data from one subject were plotted on isometric (3-D) graph paper. The body configuration thus obtained is shown in Figure 2.10. It illustrates that the data generated in this study are adequate to depict the seated position of a person. Similar side and front views, based on the data collected in the study, are presented in Chapter 3 for each of the sex and age categories.

C. Voluntary Range of Motion

1. General. In any biomechanical model of a human occupant which attempts to predict the dynamic response during impact, a knowledge of the limits of head and neck range of motion is essential. Since this study was primarily concerned with properties of the human neck in lateral bending, the original intent of this portion of the study was to determine range of motion for lateral flexion only. In the context of an automobile side-impact collision, however, lateral hyperflexion

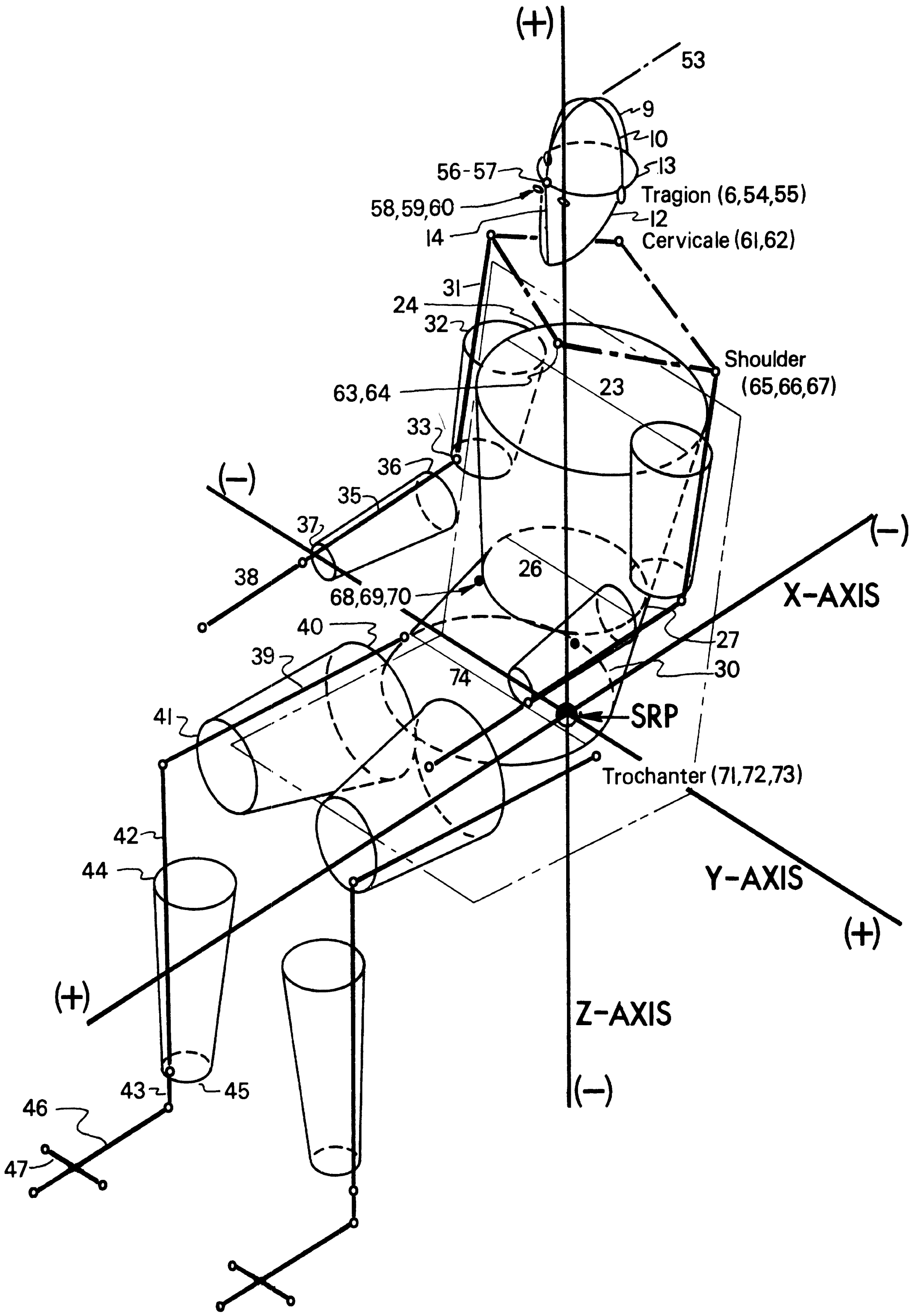


Figure 2.10 Three-dimensional representation of a seated subject, from anthropometry data. The Seat Reference Point (SRP) is the origin of the coordinate system. Numbers correspond to the anthropometry measurements listed in Figure 2.6 and described in Appendix A.

is often a complex motion, with elements of lateral bending, rotation, and flexion or extension. Voluntary lateral flexion is likewise difficult to control, since the muscles that laterally flex the head and cervical spine also tend to rotate the head. As a result of these considerations, it was decided that a three-dimensional analysis of range of motion was necessary. An expansion to a three-camera orthogonal photogrammetry system from the two-camera system used in the sagittal plane study was therefore made.

Having made the decision to use orthogonal photogrammetry, it was also decided to expand the scope of the study with regard to range-of-motion data collection (as well as to include photogrammetric anthropometry - see previous section). In addition to having subjects perform planar movements of left and right rotation (yaw), flexion and extension (pitch), and left and right lateral bend (roll), it was decided to include three combination-type movements, as follows: (1) full left rotation followed by maximum flexion toward the left shoulder; (2) full left rotation followed by maximum bending toward the rear; and (3) full right rotation followed by maximum extension toward the left shoulder. These three movements were selected as having some practical relevance to, respectively: (1) left-side impact with occupant's head turned toward the left; (2) rear impact with occupant's head turned toward the left; and (3) left-side impact with occupant's head turned toward the right. Prior to performing the range-of-motion sequence of 9 positions, the subject was positioned first with the head in the Frankfort Plane neutral position (i.e., looking straight ahead with the plane formed by left and right tragions and infraorbitales horizontal), and then in the normal sitting or neutral position. The complete test sequence for range of motion, therefore, involved 11 different positions in the order shown in Figure 2.11. A final or twelfth position in which the head was rotated about 45° to the right was used only for anthropometry of tragion.

2. Laboratory Arrangement and Equipment. A principal requirement of an orthogonal photogrammetry system is that the cameras be in a fixed relationship, 90 degrees to one another, and that they be located at known distances from a fixed "origin" which is the point in space at which the optical axes of the three cameras intersect. In the laboratory used for this study, the photogrammetry apparatus was arranged as shown in Figure 2.12. The three camera axes form the X-, Y-, and Z-axes of an inertial reference frame with origin at the "true origin." Since the true origin lay somewhere inside the subject during a test, a second or "visible origin" was rigidly attached to the test fixture, so that it could be photographed by all three cameras and was at a known distance from the true origin. This point was used during data analysis to translate coordinate points into the proper inertial reference frame (see Appendix E, Section II).

The hardware arrangement is shown in Figure 2.13. Camera mounts for the X and Y cameras were bolted to the floor, as was the test fixture with the subject seat. The Z camera was mounted on a slide track attached to the ceiling and wall and was held in alignment by a magnet. The track mounting of this camera allowed it to be brought to a convenient level for film changing and returned to precisely the proper location for testing. The subject, when seated in the test seat, faced the X camera. The Y camera photographed the subject's

Figure 2.11

Sequence of Range-of-Motion Positions

1. Frankfort or anthropometric neutral
2. Normal or neutral
3. Extension
4. Flexion
5. Right rotation
6. Left rotation
7. Right lateral bend
8. Left lateral bend
9. Left rotation plus bend toward left
10. Left rotation plus bend toward rear
11. Right rotation plus bend toward left
12. Tragion

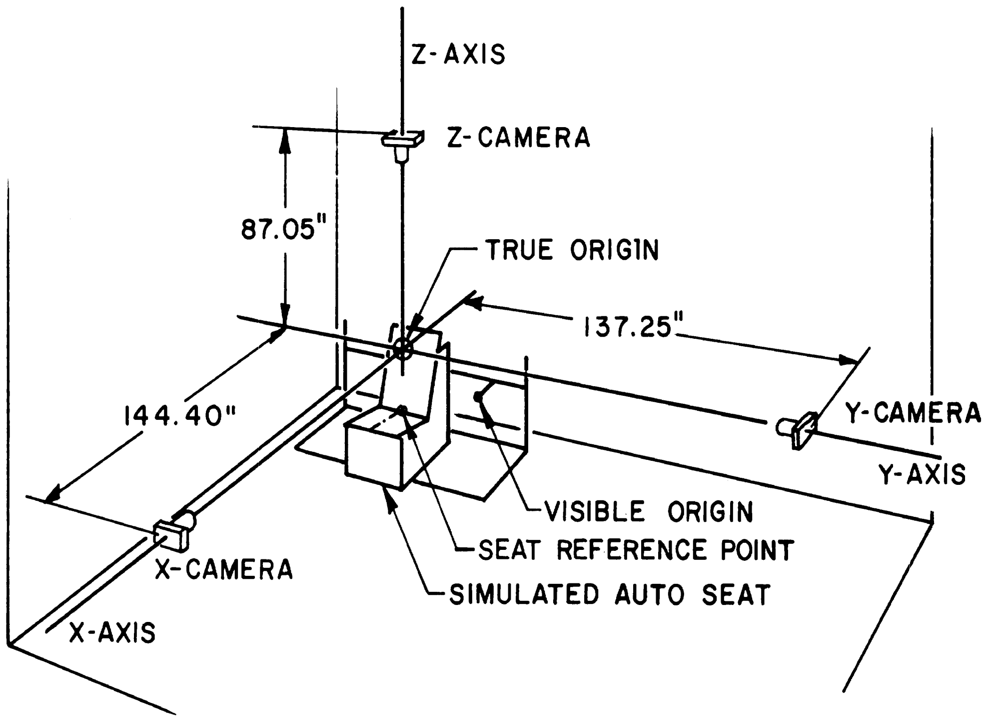


Figure 2.12 Laboratory arrangement for photogrammetric analysis of seated anthropometry and range of motion.

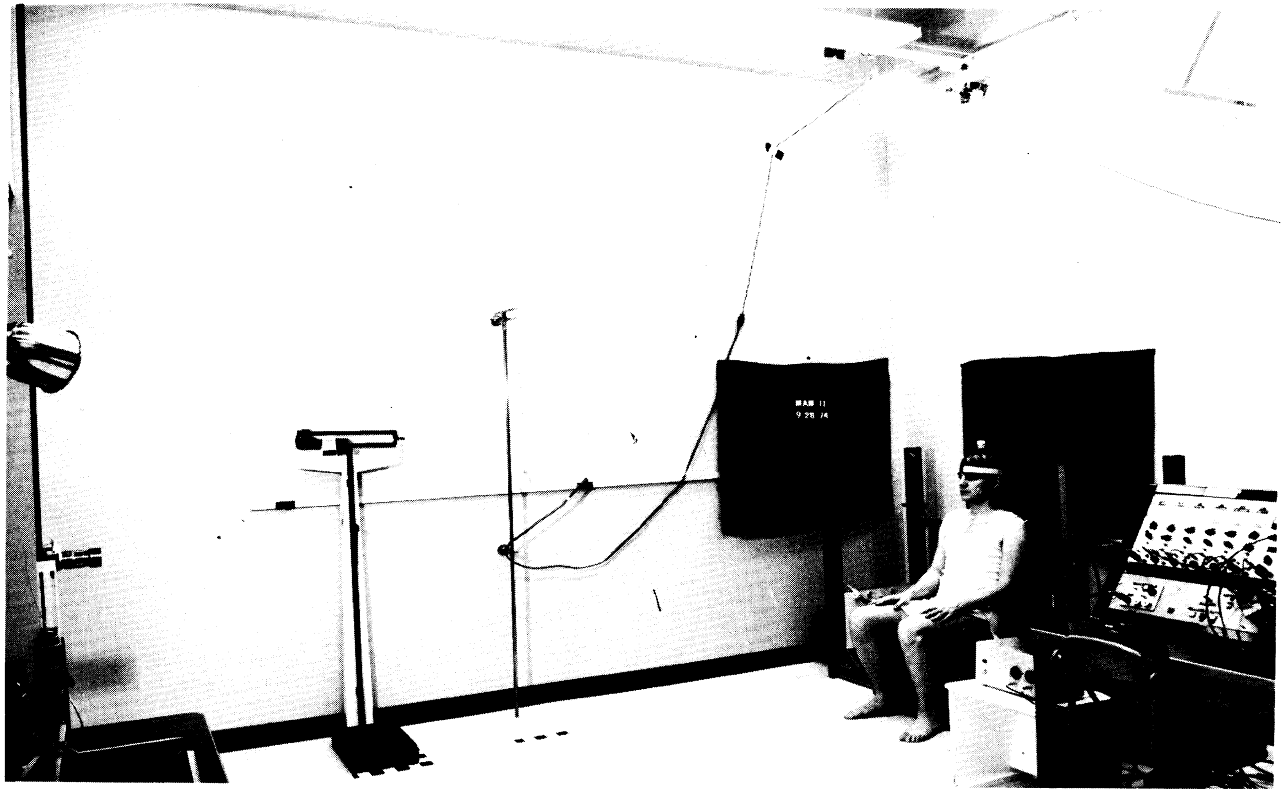


Figure 2.13 Laboratory setup for photogrammetry testing of subject showing x and z cameras.

left side and the Z camera photographed from above. All cameras were Honeywell Pentax 35mm cameras, and black and white film was used to record the data. The X and Y cameras were equipped with 105mm telephoto lenses to limit field of view and reduce parallax. The Z camera had a 55mm lens and was equipped with a motor drive unit which releases the shutter and advances the film after each photograph. A remote switch released the shutters of all three cameras simultaneously, thus assuring a consistent subject position for analysis.

3. Test Procedures and Protocol. In preparation for the photogrammetry sequence, the subject dressed in shorts and a sleeveless shirt. Reflectorized dowels were taped to the skin to identify the torso points of cervicale, suprasternale, and right and left acromion (Schanne, 1972). In addition to their use in anthropometry, these markers provided a means for determining the amount of torso movement involved when the subject performed the requested movements of the head and neck. High-contrast markers were also placed at tragion, nasion, and infraorbitale landmarks for anthropometry measurements. The photogrammetry headpiece shown in Figure 2.14 was then fitted snugly to the subject's head and the subject was positioned in the center of the test seat. This headpiece consisted of an orthogonal coordinate axis system made of aluminum and fixed to a modified liner of a welder's hood. The end points of the axes were marked by small ball bearings for easier visualization.

Upon completion of the traditional seated anthropometry (see Section B.2), the subject's head was positioned in the Frankfort plane, the sitting height measured, and the photogrammetry sequence begun. Subjects were instructed to keep their shoulders and torso

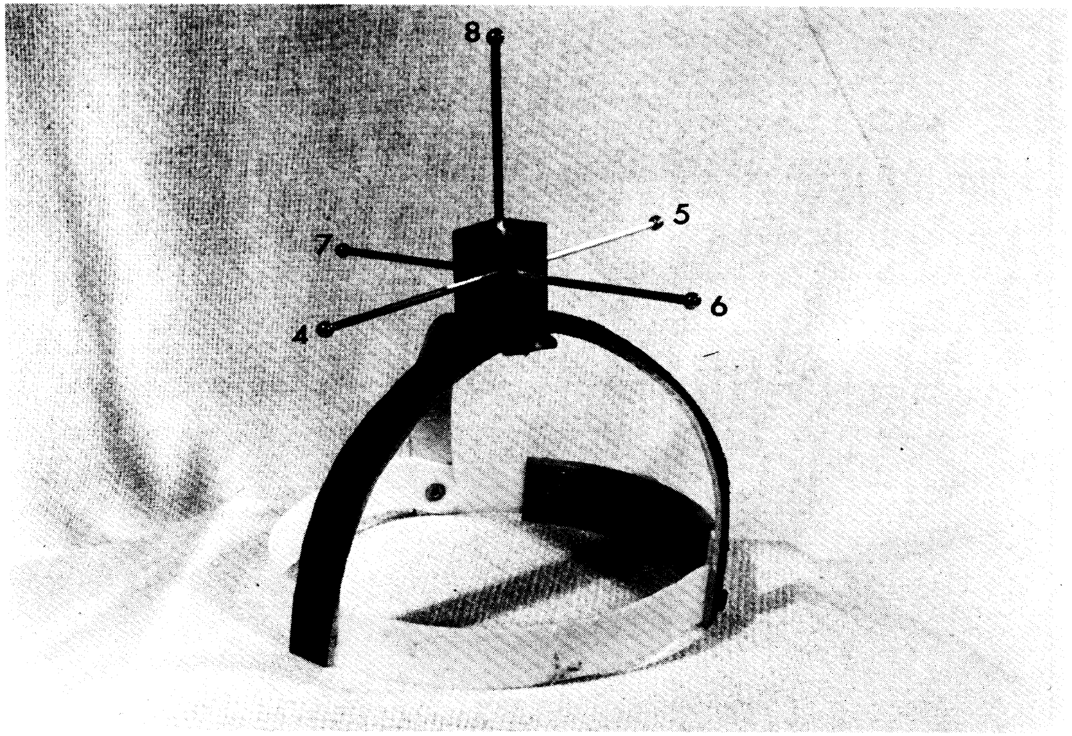


Figure 2.14 Photogrammetry test headpiece consisting of a modified liner of a welders hood with an orthogonal coordinate axis system made of aluminum.

from moving while turning the head and neck slowly and as far as possible in the requested directions. After completing a movement the subject returned to the neutral position, at which time the next movement was described. If a movement was performed incorrectly or poorly (e.g., the shoulders moved while performing a movement), the subject was asked to return to the neutral position and begin again. When the subject reached the limits of range of motion at each position (indicated by no further movement) the shutter release switch was depressed, resulting in simultaneous recording of the position by all three cameras.

Figures 2.15, 2.16, and 2.17 show oblique views of a subject at each of the positions involving a combination of movements. A description of all positions in the order performed by subjects is contained in the following list:

1. Anthropometric Neutral (Frankfort). The subject is seated in the test chair, relaxed, looking straight ahead, and the head is placed in the Frankfort Plane. This position is used to obtain the anthropometric dimensions described previously. The standardized Frankfort Plane head orientation is used because it removes the variable of random head position and allows subject-to-subject comparison of head to seat reference point dimensions and provides a standard reference for Euler angle calculations.

2. Neutral Seated Position. The subject is allowed to resume a normal relaxed sitting position, with the head in whatever orientation is comfortable to the subject. Prior to this position the subject is asked to move his head and neck so that he is not

Figure 2.15 Subject at left rotation plus flexion toward the left.

Figure 2.16 Subject at left rotation plus bend toward the rear.

Figure 2.17 Subject at right rotation plus extension toward the left.

influenced by the Frankfort position.

3. Maximum Voluntary Extension. The subject is instructed to allow the head to rotate straight back as far as possible. This position is photographed with the jaw open and relaxed to simulate a rear-end collision with complete surprise, and to obtain a maximum amount of extension. This position is referred to in the analysis as "positive pitch" of the head.

4. Maximum Voluntary Flexion. The subject is instructed to thrust the jaw straight forward, then tuck the chin under and attempt to touch the chest with the chin. This position simulates a front-end collision in which an upper torso restraint is in use.

5. Maximum Voluntary Right Rotation. The subject is instructed to turn the head to the right as far as possible without tilting the head or lifting the shoulder blades from the seat back.

6. Maximum Voluntary Left Rotation. The subject is instructed to turn the head to the left as far as possible without tilting the head or moving shoulders.

7. Maximum Voluntary Right Lateral Bend. The subject is instructed to tilt the head to the right as far as possible without turning the head or tilting the shoulders.

8. Maximum Voluntary Left Lateral Bend. The subject is instructed to tilt the head to the left as far as possible without turning the head or moving the shoulders.

9. Left Rotation combined with Flexion. The subject is instructed to first turn the head to the left as far as possible, then to "try to put the left eye on the left shoulder."

10. Left Rotation combined with Bend toward back wall. The subject is instructed to turn the head to the left as far as possible, then let the jaw relax and move the head straight back toward the wall.

11. Right Rotation combined with Extension toward left shoulder. The subject is instructed to turn the head to the right as far as possible, then, without any rotation, to tilt the head back toward the left shoulder.

4. Computation of Euler Angles

a) General. When computing or using Euler angles to describe the movement of a body in space, two factors must be known: (1) the order in which the angles are taken, and (2) the axes about which they are defined. In this study the order of Euler angles is yaw (or rotation), pitch (or flexion/extension), and roll (lateral bend). The axes about which these angles have meaning are those anatomical axes in the head related to the Frankfort Plane. That is, yaw is rotation about an axis perpendicular to the Frankfort Plane, pitch is rotation about an axis parallel to a line through left and right tragion, and roll is rotation about an axis parallel to the line formed by the intersection of the Frankfort and sagittal planes. It is important to note that this Euler angle axis system is fixed to the head and therefore its axes are parallel to the inertial or camera axes only when the subject is seated in the Frankfort position. When the head moves, the Euler angle reference system also moves and the axes of rotation for the Euler angles change relative to the torso.

Using this scheme, it can be realized that left roll or left lateral bend would be bending the head toward the left shoulder if the head were in the neutral position, and bending the head toward the rear if the head is first rotated 90° to the left. Since the positions involving a combination of movements in the test sequence first involve a full rotation of the head to the left or right and this rotation is usually greater than 60°, these three positions in order of performance may also be referred to as (1) left rotation plus flexion; (2) left rotation plus left lateral bend; and (3) right rotation plus extension. It is understood, however, that the second part of the description refers to the predominant motion occurring and that the second movement is usually more complex.

The Euler angles were computed by using the visible orthogonal coordinate system attached to the subject's head. The change in orientation of this system from the Frankfort position to the new position provided the needed information to compute the Euler angles. Since the Euler angles are defined about anatomical axes in the head, it is important that the headpiece coordinate system either be aligned with these axes, or that a correction transformation be applied to the orientation or the headpiece coordinate system prior to computing the Euler angles. The latter procedure was chosen in this study and is described in greater detail in Appendix E.

b) Data Reduction and Analysis. The technique of orthogonal photogrammetry was used first to determine the position in space (x,y,z coordinates) of the 5 points of the headpiece coordinate system in each of the 11 positions. A detailed presentation of this technique is given in Appendix E and is adopted from Chaffee (1961). In actual practice it is only necessary to "see" at least 4 points, one of which must be the top of the vertical axis, in two of the three cameras. Using the convention shown in Figure 2.14 for numbering the headpiece points, the vectors corresponding to these axes can then be computed. If we label the vector 5→4 as $\hat{I}$, 7→6 as $\hat{J}$, and 0→8 as $\hat{K}$, for the Frankfort position, and use vectors $\hat{e}_1$, $\hat{e}_2$, and $\hat{e}_3$ to represent these axes in the final rotated positions, then the Euler angles are given by:

$$\text{Yaw} = \alpha = -\tan^{-1}\left(\frac{\hat{e}_1 \cdot \hat{J}}{\hat{e}_2 \cdot \hat{I}}\right)$$

$$\text{Pitch} = \beta = -\tan^{-1}\left(\left(-\frac{\hat{e}_1 \cdot \hat{K}}{\hat{e}_1 \cdot \hat{J}}\right)\sin\alpha\right)$$

$$\text{Roll} = \gamma = \tan^{-1}\left(\frac{\hat{e}_2 \cdot \hat{K}}{\hat{e}_3 \cdot \hat{K}}\right)$$

A detailed development of these equations is presented in Appendix E. The minus signs in the equations for yaw and pitch are included so that the Euler angles are described in terms of an axis system where positive $\hat{K}$ is down and positive $\hat{J}$ is out of the right ear, as is conventional in most computer models.

In order to transfer the photogrammetric data into a form suitable for computations, the data points on film were digitized by projecting each picture onto the surface of a "Summographic Tablet" digitizer. The complete setup for digitizing including projector, tablet digitizer, high speed paper tape punch (FACIT 4070) and related electronic equipment (Scriptographics Model HW 2-11 readout and Altek Corporation interface unit) is shown in Figure 2.18. By moving a cursor over each point of interest and pushing a button, the x, y coordinates of that point were punched onto paper tape and displayed on the readout unit. The complete digitization process for each subject involved coding 376 data points, including points which code the subject number. Special codes were used to denote "unseen" points in each photo, as were points to denote "between-picture" reference points. On each picture, the visible origin, headpiece, and torso anthropometry points were coded. At the beginning of each camera sequence, two points were coded to correct for camera or projector roll. Figures D.1-D.3 in Appendix D illustrate the order of coding of points for the 36 pictures taken of each subject.

Two computer programs, included as Appendix F, were written for analyzing the photogrammetric data. One program calculates the seated anthropometric measurements, the other computes range of motion at each position in Euler angles. This latter program makes corrections for camera roll and corrects for headpiece tilt relative to the anatomical Euler angle axes of the head. The output is a set of 33 Euler angles which describe the relation of positions 2 through 11 to the Frankfort position. These data were then keypunched and input to computer files on the Michigan Terminal System (MTS) for statistical analysis and correlation computations.

D. Active Tests

1. General. A question of considerable importance to under-

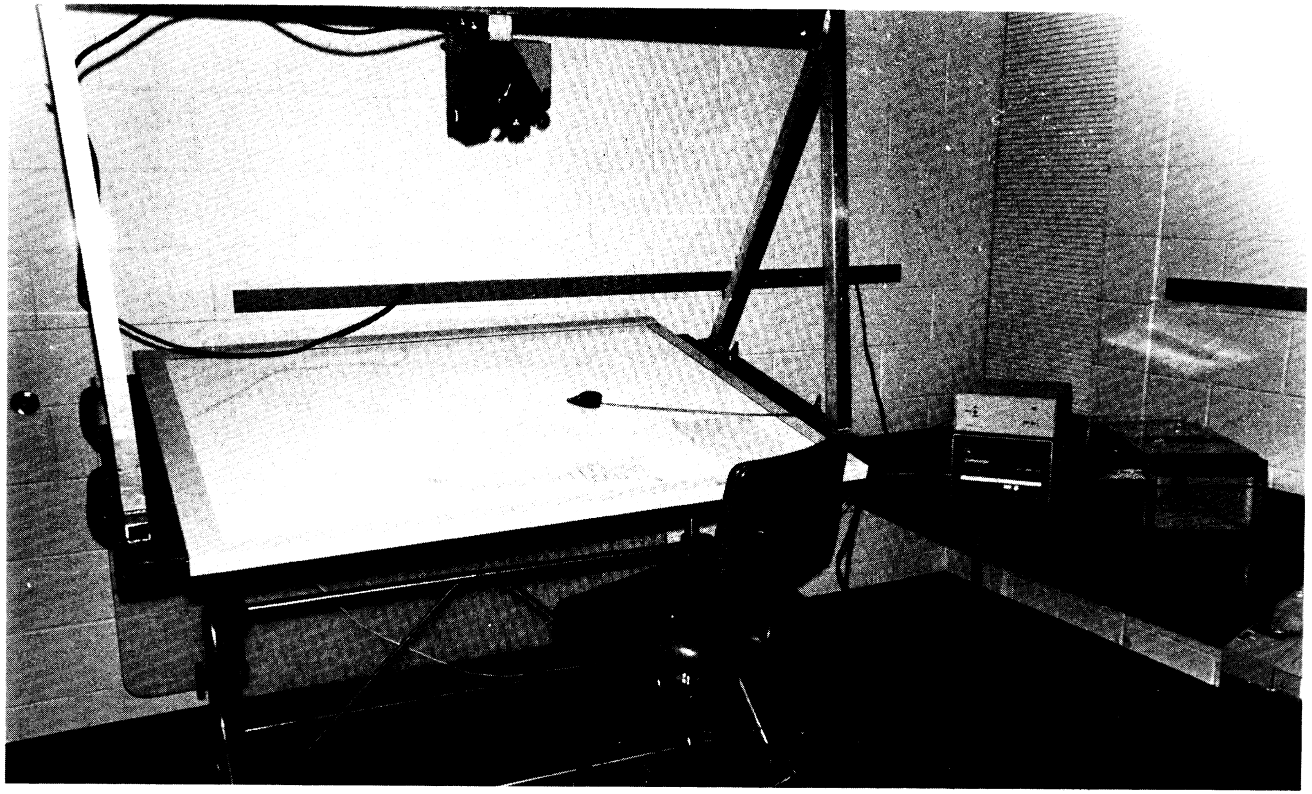


Figure 2.18 Digitizing equipment for converting points on photographs to digitized x-y coordinates on paper tape.

standing and modeling the response of the head and neck during impact is this: To what extent do the neck muscles prevent head movement and therefore whiplash injury? Or, conversely, at what impact levels do the neck muscles become ineffective in preventing injury? While the answer is by no means simple, two factors have a direct influence on the answer. One is the force or strength which the neck muscles can exert to restrain the movement of the head. The second factor, which is primarily important during a surprise impact, is the reaction time of the neck muscles, or the time it takes the muscles to reach their maximum force. This time can be divided into two parts: (1) the time it takes for muscle activity to begin after head movement (reflex time); and (2) the time from beginning of muscle activity to maximum contraction force (contraction time). The active test portion of this study was designed to measure both the muscle strength and reflex times of the sample population described in Section 2.A, and thereby to determine how these factors vary with age and sex, and ultimately how they affect response to impact. Two tests were run on subjects to acquire these data. The first test, referred to as the head jerk or reflex test, recorded the subjects' head acceleration and muscle activity in response to a known and sudden force applied to the head in the lateral direction. The second test, referred to as the strength test, measured the maximum voluntary isometric pull that the subjects could exert by using their neck muscles and pulling in the lateral direction.

2. Experimental Setup and Procedures

a) Electronic Equipment. Figure 2.19 shows the ex-

Figure 2.19 Experimental setup for active testing of subjects showing electronic equipment, subject in test seat, and research assistant.

perimental setup for active testing of subjects, including the amplifying, recording, and monitoring equipment. Complete control of the experiment was provided by the control console shown in front of the researcher. All signals passed through 6 channels on this unit and could be further amplified or filtered prior to recording on magnetic tape. A meter at each channel provided for monitoring of the signals to ensure that all instrumentation was working properly. A 7th channel provided logic level and strobe pulses for labeling tests and marking events on the magnetic tape. Control of the reflex test weight drop and starting and stopping of the tape recorder were also provided for by switches on this console.

The tape recorder is a 7-channel Ampex Model PR-500 with 7 channels of FM record and reproduce and a voice channel. Tape speed was set at 1-7/8 inches per second for this study, and all channels were calibrated and adjusted for minimum distortion and an input-to output gain ratio of 5:1. During a test session, the outputs of two channels of the tape recorder were displayed on the two channel Brush recorder (Model 220) shown at the researcher's right hand. Additional signal monitoring capability was provided by the Model 564 Tektronix oscilloscope (behind the researcher). The small box to the lower left of the console provided for preamplification of the accelerometer and small strain ring signals, and included analog circuitry for computation of angular head accelerations.

b) Reflex Test. Figure 2.20 shows a subject seated for reflex testing with the left shoulder against a brace to prevent torso movement. A pulsed force was applied near the center of gravity of the head by means of a band placed tightly around the subject's head just

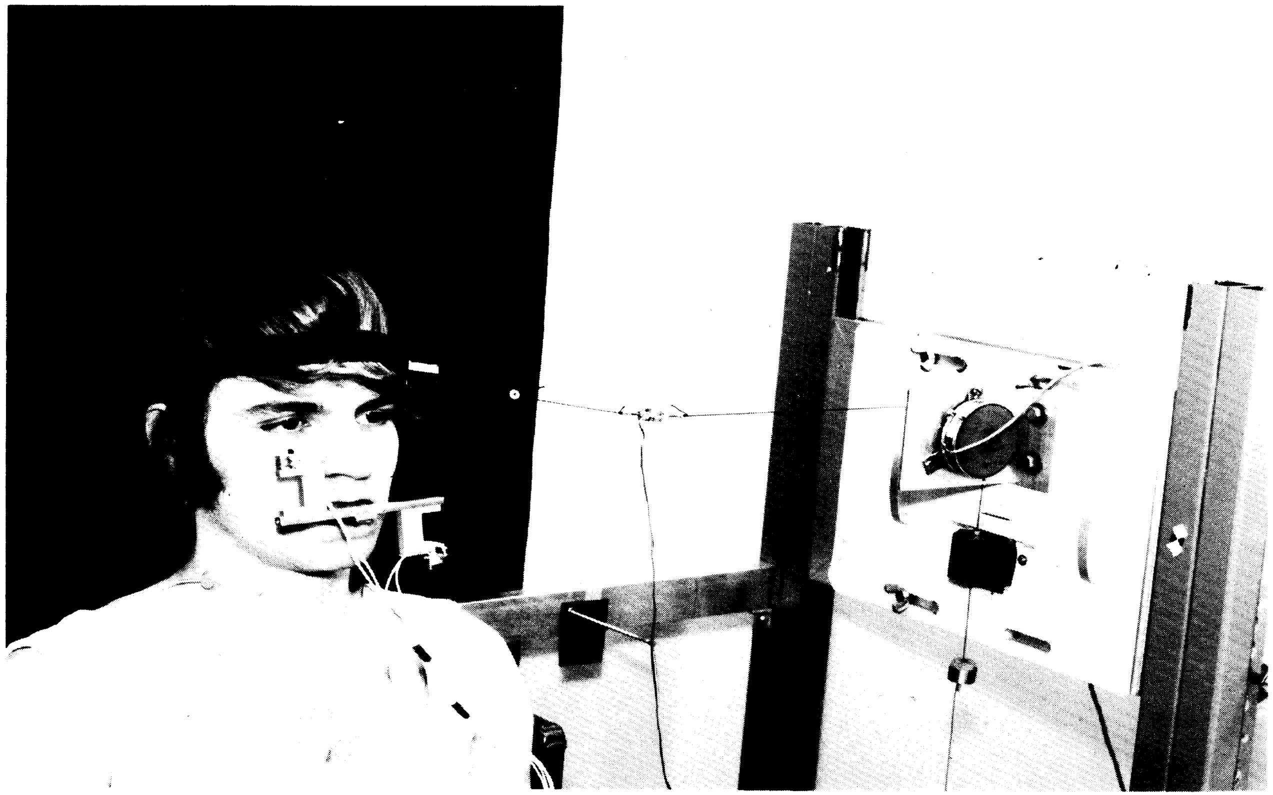


Figure 2.20 Closeup of subject ready for reflex test showing accelerometers mounted on bite bar, strain ring in weight drop line, and weight release mechanism.

over the ears. Attached to this band is a nylon line which was draped over a pulley, threaded through a one-pound weight, and connected to a small "stop" weight at the other end. The one-pound weight was held in place by an electromagnet and released by the researcher at the control console. A small strain ring in the nylon line measured the tension or force applied to the head by the weight drop. Drop distances of four inches were used in most cases but were increased to 6 or 8 inches if necessary. A typical input force profile is shown in Figure 2.21.

Muscle activity of the sternomastoid muscle group on the subject's right side was measured during the test by two surface electrodes placed as shown in Figures 2.22 and 2.23. A third ground electrode was placed over C7 as shown. EMG activity was monitored on the oscilloscope during testing so that the weight could be dropped when the subject was relaxed.

Head movement was detected and measured by four accelerometers contained in two biaxial units made by Entran Devices, Inc. (Model EGAL2-125C-10D). These accelerometer units were fastened to the structure as shown and fixed to the subject's head by means of a bite plate which the subject held in his mouth. This consisted of an aluminum plate to which was molded a dental impression compound in which the subject had made a cast of his teeth. The accelerometer axes were oriented as shown in Figure 2.24, and, assuming planar movement of the head during the jerk, angular and linear acceleration of the center of gravity of the head were calculated by the equations presented in the data analysis section of this chapter.

Accelerometer output signals and the force transducer signal

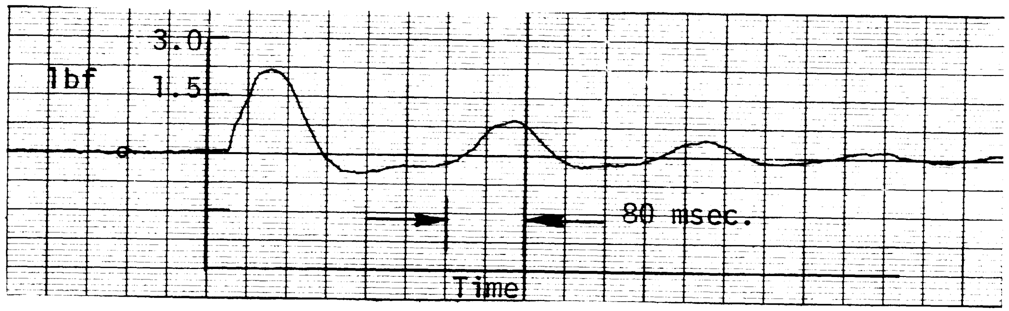


Figure 2.21 Typical force profile produced by weight drop as measured by in-line strain ring.

Figure 2.22 Photograph of subject's neck showing placement of EMG electrodes.

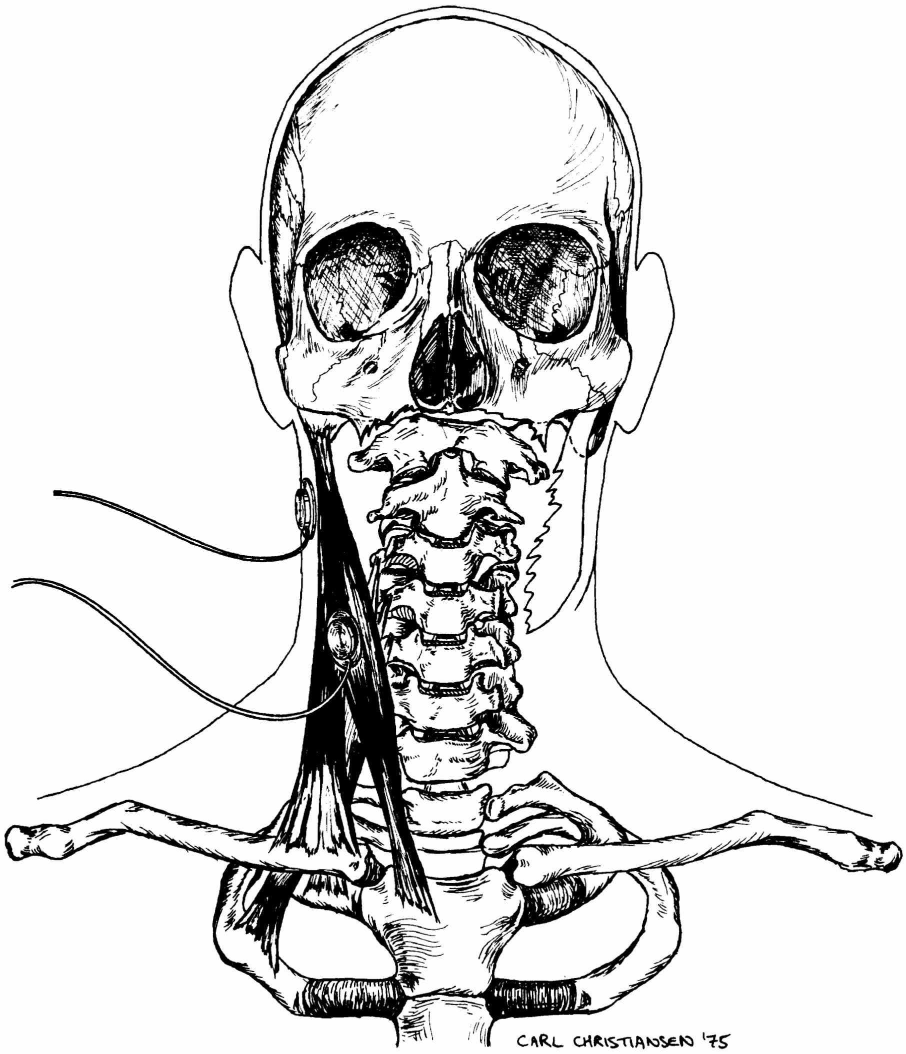


Figure 2.23 Cut-away drawing illustrating placement of EMG electrodes relative to head and neck muscles.

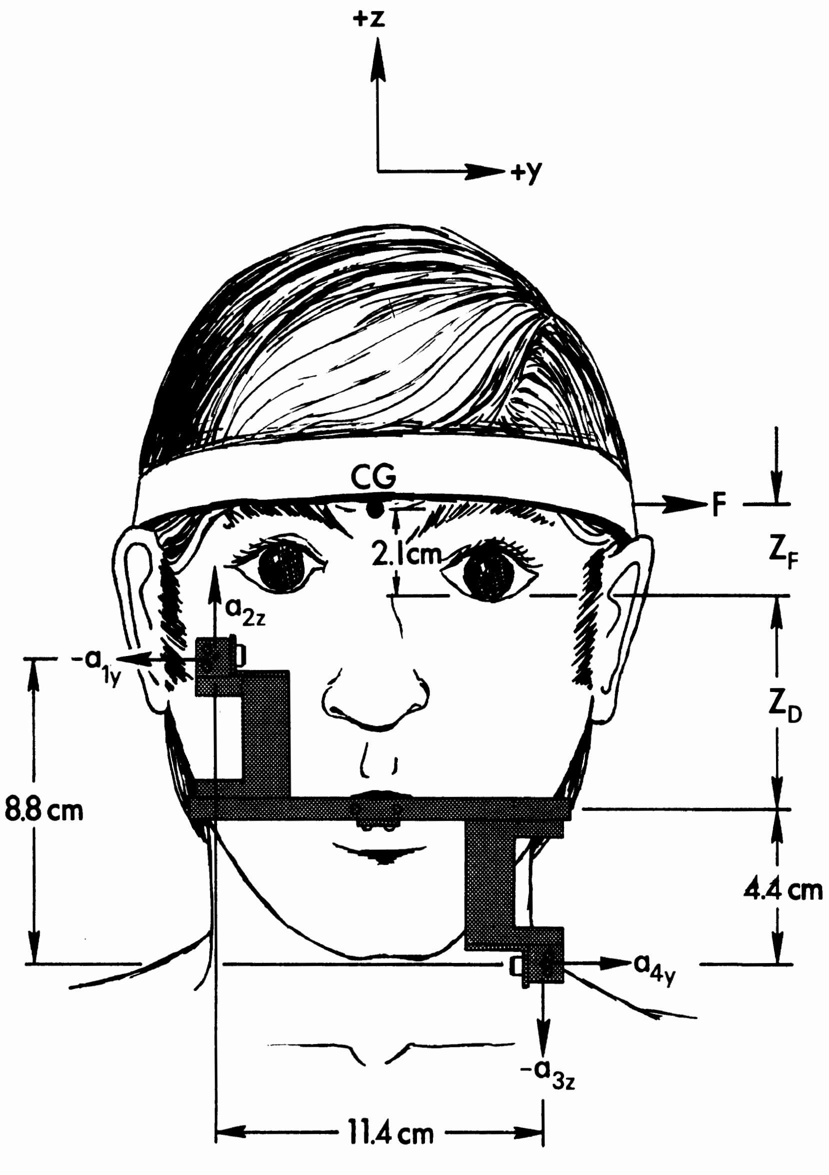


Figure 2.24 Drawing of subject with accelerometer piece in mouth illustrating critical dimensions and directions of accelerometer axes.

were preamplified and input through console channels 2, 3, 4, 5, and 6 to corresponding channels of the tape recorder. EMG signals were input through channel 1 on the console to channel 1 of the recorder.

Prior to reflex testing, each subject was given instructions to face straight ahead, close his eyes, and relax, but to attempt to keep his head upright when he felt the jerk. A second researcher observed the subject during the tests to ensure that the head did not rotate. If necessary, appropriate adjustments were made in the headband position to achieve planar motion. A series of several tests was run on each subject to obtain an average measure of reflex time.

c) Strength Test. Figure 2.25 shows a subject performing the strength test using the right neck lateral flexor muscles. The head strap was placed around the head above the ears and isometric tension measured by the large strain ring near the restraining fixture. Subjects were tested from both sides, although EMG activity was recorded from only the right sternomastoid muscles. After an initial training pull to check equipment and have the subject "get the feel", testing was begun. Subjects were asked to build to a maximum force in 1 or 2 seconds and to hold this level for a count of 4 seconds. Three trials were run from each side with one-minute rests between each trial. The amplified strain ring output was displayed on one channel of the Brush recorder in addition to being input to channel 6 of the tape recorder, so that the results could be examined immediately. If there was a significant difference between trials, subjects were asked to perform additional runs until consistency was achieved. During the tests a second researcher observed the subject to ensure that only the neck muscles were being used (i.e., the subject did not

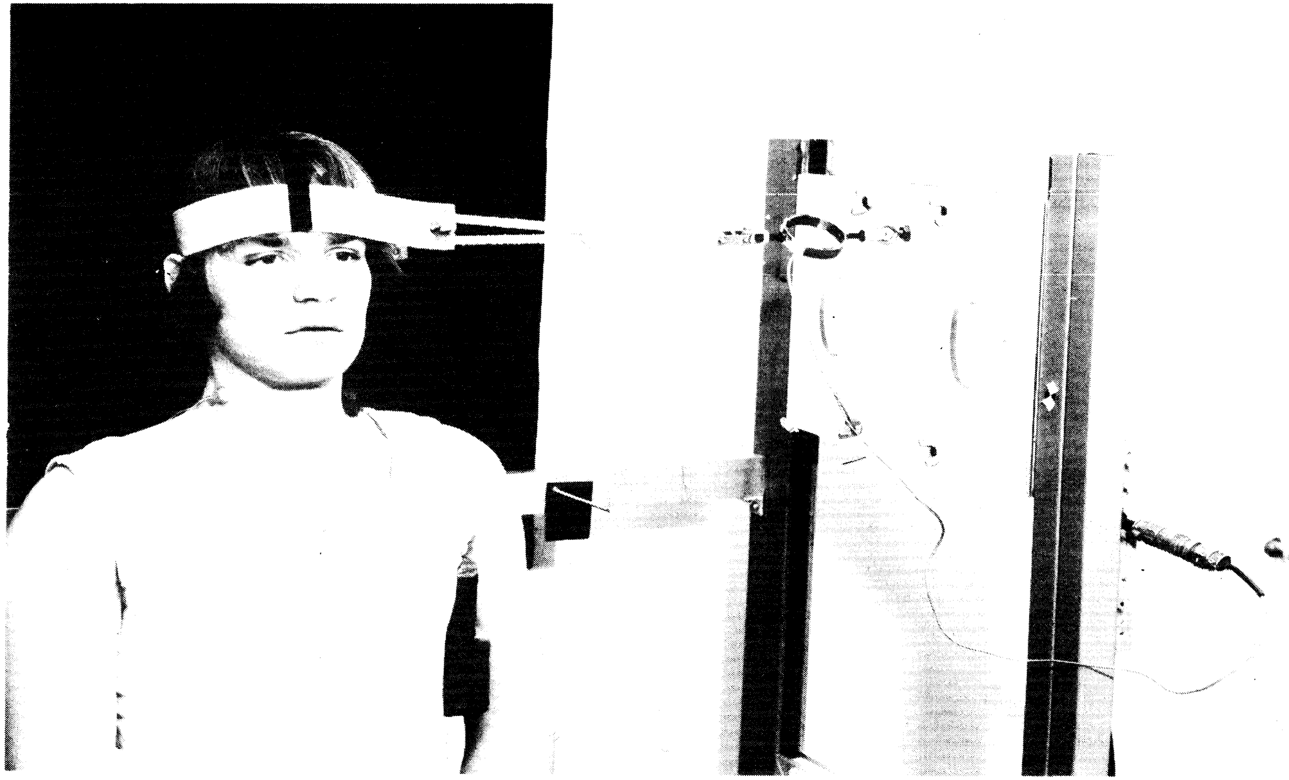


Figure 2.25 Subject performing lateral neck strength test.

lift off the seat) and that the effort was in the lateral direction. A side brace was available for the subject to react against.

3. Data Analysis

a) Reflex Time. Reflex time is defined as the time from onset of head acceleration to the time at which EMG signals show an increase in muscle activity. During testing the acceleration signal, a_1y, and the EMG signal were output from the tape recorder to the 2-channel Brush recorder. Because of the time delay caused by the distance between recording and playback heads on the tape recorder, it was possible to start the Brush recorder after the test and thereby display these two signals during the testing without affecting the subject's response time (i.e., without cueing the subject). Figure 2.26 shows a typical acceleration and EMG response to a weight drop of 4 inches. The onset of head acceleration is clearly indicated by the rapid rise in the acceleration signal. Similarly, the increase in EMG activity is noted by an initial spike of activity, followed by further increased activity. The time between these two points is the reflex time. While it would theoretically be possible to determine this time by computer analysis, in practice the EMG signal was not always as clear as the one shown, and a visual determination of this point was found to be more dependable. Reflex times were therefore determined by marking and measuring distances manually on these strip charts. Where increased EMG signals were questionable and not obvious, a check of the reflex time was made by a second person. If there was poor agreement on the result, the data were discarded. Since the strip charts were produced following each test, it was possible to

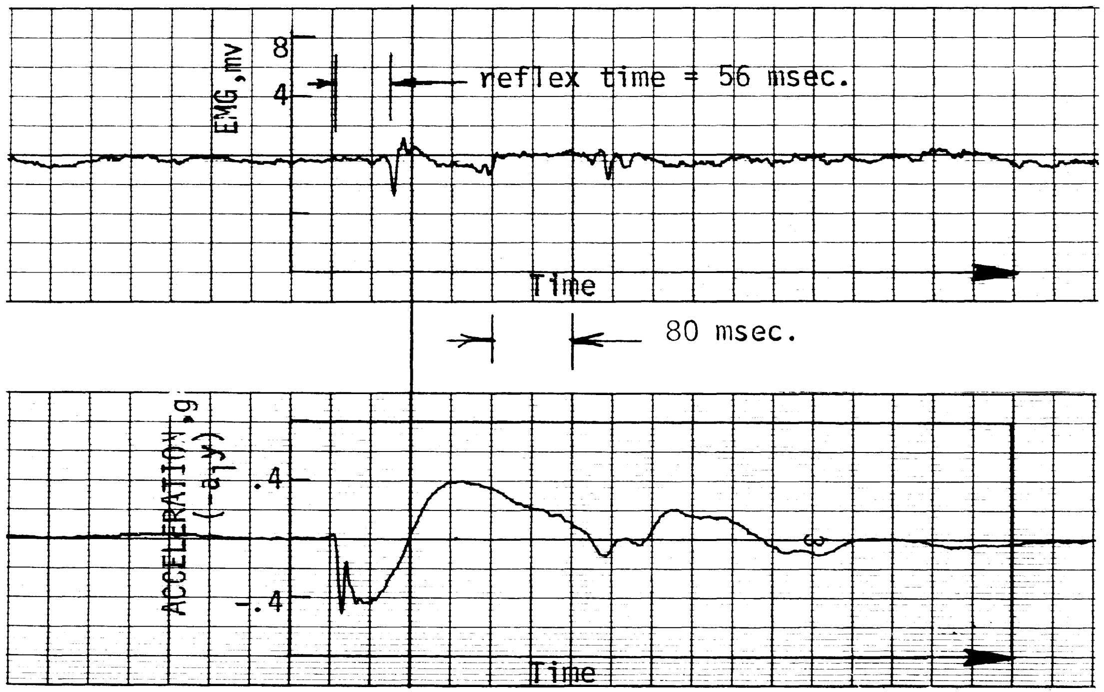


Figure 2.26 Typical EMG and acceleration response $(-a_1y)$ to head jerk illustrating reflex time measurement.

check the response immediately and repeat the tests until a set of 5 or 6 "good" responses were obtained. Often a poor response could be improved by increasing the weight drop distance or by moving the electrodes. The reflex times observed for the several tests on each subject were then averaged and the results keypunched for input to file storage on the University of Michigan IBM 370 computer system (MTS).

b) Strength Test. Figure 2.27 illustrates a typical series of force curves and EMG activity obtained during strength testing. As with the reflex time data, these results were produced at the time of testing and the data analyzed manually. The average of the three runs from each side was keypunched and input to files on MTS for statistical and correlation analysis.

c) Head Acceleration. The primary value of the acceleration signals, other than for determining reflex time, is that they provided the basic criterion for comparing computer simulation results of the head jerk test with actual experimental results. For example, the angular acceleration profile produced by a computer model, given the experimental force profile and point of application to the head, could be compared with the experimental angular acceleration curve. This exercise was performed for 4 subjects at the anthropometric extremes of the sample; the results are presented in Chapter 3, Section F. The force profile and acceleration signals were digitized by hand and angular acceleration computed by a digital computer program. Comparison of the computer results with experimental results allowed for determining an appropriate value for a neck stiffness constant, K, for

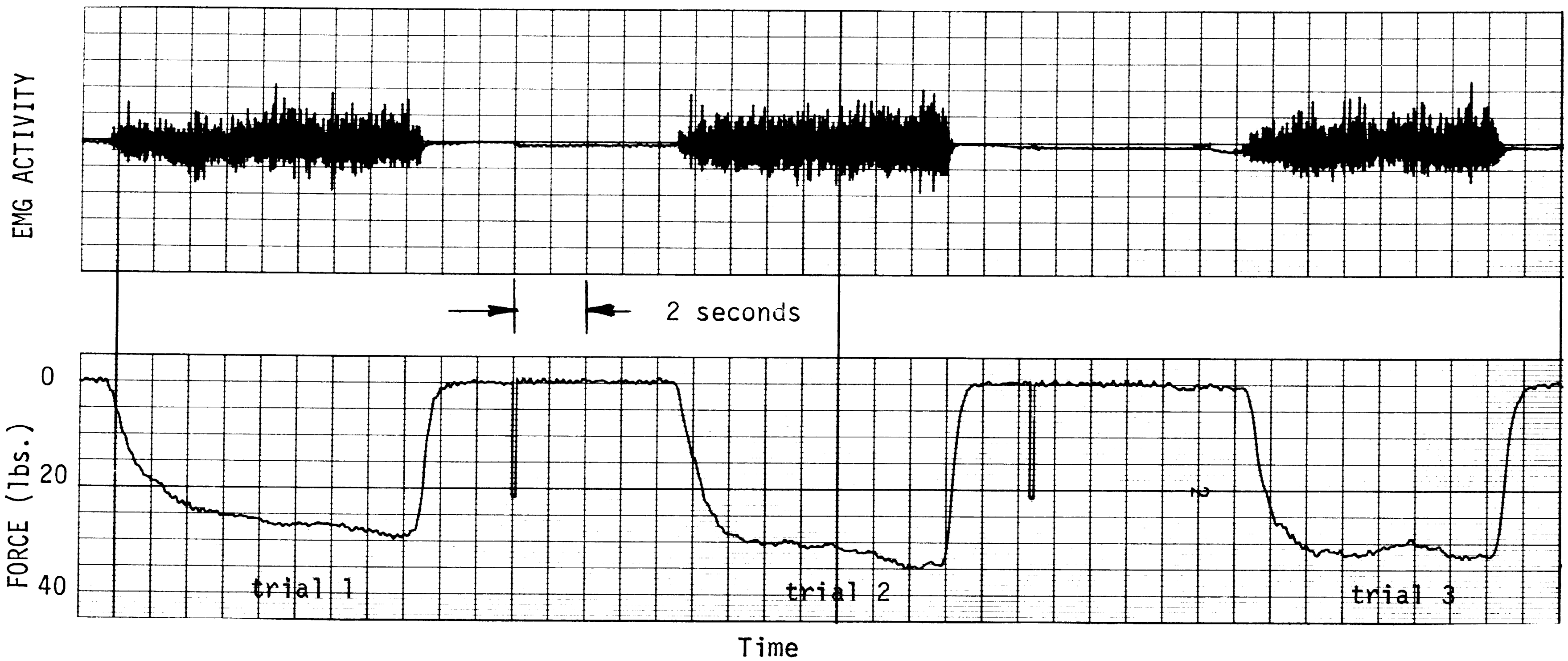


Figure 2.27 Force curves and EMG activity for a series of three strength tests using right neck muscles.

the MVMA 2-D model, which had previously had little experimental basis for this value.

Referring again to Figure 2.24, the equations for calculating the accelerations at the center of gravity of the head (Nabee, A. HSRI personal communication) are given by:

$$(1)\ \text{ang. accel. } (\alpha) = \frac{(y_4 - y_1)(a_2z - a_3z) - (z_2 - z_3)(a_1y - a_4y)}{(y_4 - y_1)(y_2 - y_3) - (z_2 - z_3)(z_4 - z_1)}$$

$$(2)\ \text{ang. vel.}^2\ (\omega^2) = \frac{(y_2 - y_3)(a_1y - a_4y) - (z_4 - z_1)(a_2z - a_3z)}{(y_4 - y_1)(y_2 - y_3) - (z_2 - z_3)(z_4 - z_1)}$$

$$(3)\ \text{linear accel. in z direction} = a_{cz} = \frac{a_2z + a_3z}{2} - \frac{(y_2 + y_3)}{2}\alpha + \frac{(z_2 + z_3)}{2}\omega^2$$

$$(4)\ \text{linear accel. in y direction} = a_{cy} = \frac{a_1y + a_4y}{2} + \frac{(z_1 + z_4)}{2}\alpha + \frac{(y_1 + y_4)}{2}\omega^2$$

$$(5)\quad \text{magnitude of linear acceleration} = |A| = \sqrt{a_{cy}^2 + a_{cz}^2}$$

where a_1y, a_2z, a_3z, and a_4y are the signals from the 4 accelerometers and y_1, y_2, y_3, y_4, z_1, z_2, z_3, and z_4 are the distances from the head center of gravity to the accelerometers. Ewing and Thomas (1972) have reported the average z distance of the head c.g. from tragion to be 2.13 cm. A value of 2.1 cm was therefore used in this study.

For the geometry and dimensions shown in Figure 2.24, the equations reduce to:

$$(6)\ \alpha = -.217(a_2z - a_3z) + .1675(a_1y - a_4y)$$

$$(7)\quad \omega^2 = -.217(a_1y - a_4y) - .1675(a_2z - a_3z)$$

$$(8)\quad a_{cz} = .5(a_2z + a_3z) + [2.1 + z_D][.217(a_1y - a_4y) + .1675(a_2z - a_3z)]$$

$$(9)\quad a_{cy} = .5(a_1y + a_4y) - [2.1 + z_D][-.217(a_2z - a_3z) + .1675(a_1y - a_4y)]$$

CHAPTER 3

RESULTS

A substantial quantity of data was produced during this study. Some of the data relate only to specific characteristics of neck motion in the lateral direction. However, many of the data are related to broader aspects of occupant protection, such as practical limits to range of neck motion and the location of body landmarks for a seated person. Since much of the emphasis in this study was to gather data which can be used in biomechanical models, the results are presented in a manner useful to that type of activity. Tabular and statistical summaries, based on the primary variables of the study, are presented in this chapter for certain anthropometric and range-of-motion measures and for the muscle reflex time and strength tests. Complete statistical summaries of all results, by subject category, may be found in Appendices B and C.

A. Subject Pool

1. Final Composition of Subject Pool. As indicated previously, the majority of subjects for the lateral motion study were obtained from the sagittal plane study subject pool. The final subject pool consisted of 96 adults (48 females and 48 males), of whom 67 (35 females, 32 males) returned from the previous study. As indicated in Table 3.1, the final subject categories closely matched the original statistical design. In two categories (62-74 yr. females and 35-44 yr. males), it was not possible to locate enough subjects of average stature. In those cases, additional short and tall subjects were used to balance the stature categories. Table 3.1 also shows that the large majority

Table 3.1

FINAL SUBJECT POOL CONFIGURATION

		AGE GROUP IN YEARS											
		18 - 24			35 - 44			62 - 74			AGES COMBINED		
		ORIG.	FINAL	RET'NS	ORIG.	FINAL	RET'NS	ORIG.	FINAL	RET'NS	ORIG.	FINAL	RET'NS
FEMALES	SHORT	3	3	3	3	3	3	3	4	4	9	10	10
	MED	10	10	2	10	10	7	10	8	6	30	28	15
	TALL	3	3	3	3	3	3	3	4	4	9	10	10
	TOTAL	16	16	8	16	16	13	16	16	14	48	48	35
MALES	SHORT	3	3	2	3	4	3	3	3	3	9	10	8
	MED	10	10	2	10	8	6	10	10	8	30	28	16
	TALL	3	4	2	3	3	3	3	3	3	9	10	8
	TOTAL	16	17	6	16	15	12	16	16	14	48	48	32
ALL SUBJECTS COMBINED	SHORT										18	20	18
	MED										60	56	31
	TALL										18	20	18
	TOTAL										96	96	67

of subjects needed in the 35-44 and 62-74 age groups were recruited from participants in the sagittal plane study. Relatively few (fewer than 50%) of the young subject group returned, reflecting the preponderance of transient university students in that group. In all, 70% of the needed subjects came from the sagittal plane study subject pool. This large percentage made it possible to achieve the intent of the lateral motion study, which was to be able to combine the data from both neck motion studies as if all data had been obtained from the same subjects.

2. Comparison of Key Anthropometric Measurements. One method used to check the assumption of similar subject pools involved comparing three measurements often used to describe a population: weight, stature, and erect sitting height. Table 3.2 shows a comparison of the lateral motion study results with those of two previous studies--the sagittal plane study and the U.S. Public Health Survey report cited previously. For the lateral motion study, it was intended that the subject pool: (1) be representative, in age and stature distribution, of the adult population of the United States, and (2) duplicate, insofar as possible with 96 subjects, the dimensional characteristics of the 180 subjects of the sagittal plane study. Table 3.2 shows that, in most categories, stature and erect sitting height matched very closely. Although subjects were not selected on the basis of weight, weights also matched well. When the data from all subjects are combined, it is evident that the 96 lateral motion study subjects represent very accurately the 179 subjects of the sagittal plane study and the 6672 PHS subjects. Table 3.3 shows the average difference between the means of the six subject categories for each of

Table 3.2

SUBJECT POOL ANTHROPOMETRY - COMPARISONS BETWEEN SUBJECT POOLS & US PHS RESULTS

		AGE GROUP IN YEARS											
		18 - 24			35 - 44			62 - 74			AGES COMBINED		
		LAT	SAG	PHS	LAT	SAG	PHS	LAT	SAG	PHS	LAT	SAG	PHS
FEMALES	N =	16	31	534	16	30	784	16	31	299	48	92	3581
	WEIGHT(kg)	57.3	58.6	57.7	59.3	59.5	64.5	66.0	65.2	65.5	50.8	61.1	63.6
	STATURE(cm)	162.3	163.1	162.1	160.5	161.4	161.3	156.3	158.5	156.2	159.7	161.0	160.0
	ERECT SITTING HT(cm)	86.2	85.8	85.3	85.4	85.4	85.6	82.0	82.7	81.5	84.6	84.6	84.6
MALES	N =	17	30	411	15	30	703	16	27	265	48	87	3091
	WEIGHT(kg)	71.6	71.4	71.8	78.5	83.5	77.3	70.7	72.9	71.8	73.4	76.0	75.5
	STATURE(cm)	175.0	174.9	174.5	173.7	173.9	174.0	169.8	171.3*	169.9	172.8	173.4	173.2
	ERECT SITTING HT(cm)	91.5	91.1	90.9	89.7	90.5	91.2	88.8	88.8	88.1	90.1	90.2	90.4
ALL SUBJECTS COMBINED	N =										96	179	6672
	WEIGHT(kg)										67.1	68.4	69.1
	STATURE(cm)										166.3	167.1	166.1
	ERECT SITTING HT(cm)										87.3	87.3	87.3

* Unbalanced cells: 6 short, 10 med, 11 tall - skewed to taller stature

Note: "Average" (not 50%ile) used for US PHS data.
Weight is reported average minus 2 lbs for clothing.
Mean used for HSRI data.

the three measures. In all cases of stature and sitting heights, the average difference was less than one centimeter. No statistically significant differences were found between the means.

TABLE 3.3

Average Difference of Means in Six Subject Categories by Sex and Age:

	Weight (kg)	Stature (cm)	Erect Sitting Height (cm)
1) Between Lat Mot & US PHS	1.4	0.33	0.73
2) Between Sag Plane & US PHS	2.3	0.88	0.58
3) Between Lat Mot & Sag Plane	1.6	0.95	0.38

B. Anthropometry

The anthropometry data for this study were collected in a manner compatible with the four objectives outlined in Chapter 2. The measures are intended to describe the person sufficiently to allow comparisons with other study results, to determine the location of major body masses, and to locate important landmarks for the seated occupant. The results summarized in this section are presented in that order.

A total of 84 measures were obtained from each of 96 subjects. Certain of these were used to derive an additional 27 measures. In addition, the data were statistically analyzed with respect to various categorizations of subjects. It would be impractical to present all of the data summaries for all of the measurements in the text of this report; these may be found in Appendix B. However, selected measurements are presented in Tables 3.5 through 3.9, to illustrate the nature and usefulness of the results.

1. Basic Results. The basic results of the anthropometric study are contained in Appendix B. Each table in Appendix B is a list of 84 measured and 27 derived variables for a specific group of subjects, as follows:

Table B.1	All Subjects Combined
Table B.2	All Female Subjects (Ages Combined)
Table B.3	All Male Subjects (Ages Combined)
Table B.4	Females, Age 18-24
Table B.5	Females, Age 35-44
Table B.6	Females, Age 62-74
Table B.7	Males, Age 18-24
Table B.8	Males, Age 35-44
Table B.9	Males, Age 62-74

For each measurement variable, the following statistical summary is given:

Number of Subjects

Mean (Average)

Standard Deviation

Standard Error of Mean

Range (Minimum and Maximum)

Coefficient of Variation (Std. Dev./Mean)

5th, 50th and 95th Percentiles (Calculated)

Of special interest to those concerned with seated-position data is a summary of 24 derived measures which constitute the last 24 measurements reported in each table. These are the average X, Y, and Z positions of eight body landmarks with respect to the Seat Reference

Point. Using this information, the position, in space, of any landmark may be calculated with respect to any other landmark (for example, the location of the pupil of the eye with respect to the trochanter [hip]).

It should be noted that the same anthropometrist measured the subjects in both the sagittal plane and lateral motion studies. This precaution was taken to reduce the minor and usually consistent "measurer error" that can occur because different anthropometrists take the same measurement in a slightly different manner.

To check the accuracy and repeatability of the measurements taken by the anthropometrist, a detailed comparison was made with the 25 head, neck, and body measurements that were duplicated in the sagittal plane and lateral motion studies. Fifteen female and six male subjects who participated in both studies were selected for the detailed comparison. Eight bony-landmark measures and 16 soft-tissue measures were compared on a subject-by-subject, measurement-by-measurement basis. The average absolute difference for the 504 measurements thus represented was 7.5 millimeters. Only absolute differences were used in the comparison to make it as conservative as possible (that is, no sign convention was assigned such that a measurement that was larger in one study would be balanced by a measurement larger in the other study). The average difference for all bony-landmark measurements (which might be expected to change less with time than soft-tissue results) was slightly less than 6.1 mm. This is considered good repeatability, especially since three of the bony-landmark measures (stature, erect sitting height, biacromial breadth) are taken across many articulations, each of which can cause variation. When no articulations are involved, repeatability improves (for example, the average difference in bitragion diameter was 2.3 mm). Table 3.4 is a brief summary of the repeatability check.

Table 3.4

Repeatability of Duplicated Measures on the Same Subject

	Average Absolute Difference, mm.		
	Bitragion Diameter	8 Bony Landmarks	8 Bony + 16 Soft-Tissue
15 Females	2.0	6.5	8.3
6 Males	3.2	5.2	5.7
21 Subjects	2.3	6.1	7.5

2. Comparisons with Sagittal Plane Study. The three measurements (weight, stature, sitting height) used to establish the comparability of our subject pool with the U.S. adult population are contained in Table 3.2 and will not be reiterated here. However, 22 other measurements that were taken were duplicates of measures obtained in the sagittal plane study. Most of these were head and neck measurements. Twelve of the 22 (four each of head, neck and body dimensions) were analyzed and compared to the results of the sagittal plane study. The results obtained in the lateral motion study, and the comparable data from the sagittal plane study, are presented in Tables 3.5, 3.6, and 3.7.

Table 3.5 compares four head measurements. Bitragion diameter and head length are measured between bony landmarks; head circumference and sagittal arc length are measured over hair and skin surface. Inspection of the results reveals great similarity between

Table 3.5

COMPARISON OF ANTHROPOMETRY RESULTS - MEAN VALUES OF SELECTED HEAD MEASUREMENTS

		Age Groups in Years							
		18-24		35-44		62-74		Ages Combined	
		Lat.	Sag.	Lat.	Sag.	Lat.	Sag.	Lat.	Sag.
Females	N=	16	31	16	30	16	31	48	92
	Head Cir.=	56.0	55.5	55.3	55.8	55.8	56.0	55.7	55.8
	Bitragion dia.=	13.0	13.1	13.1	13.3	13.5	13.4	13.2	13.3
	Head Len.=	17.9	17.8	18.0	17.9	18.1	18.0	18.0	17.9
	Sagittal arc len.=	35.2	35.2	34.7	35.4	34.2	34.6	34.7	35.1
Males	N=	17	30	15	30	16	27	48	87
	Head cir.=	58.6	57.7	58.1	58.2	58.1	57.8	58.3	57.9
	Bitragion dia.=	13.5	13.7	14.0	14.4	14.3	14.3	13.9	14.1
	Head len.=	19.3	19.0	19.1	19.1	18.9	19.2	19.1	19.1
	Sagittal arc len.=	36.7	36.8	35.4	36.1	35.5	35.2	35.9	36.1
All Subjects Combined	N=	All dimensions are in cm.						96	179
	Head cir.=							57.0	56.8
	Bitragion dia.=							13.6	13.7
	Head len.=							18.6	18.5
	Sagittal arc len.=							35.3	35.6

the subject groups in both studies, since means (and standard deviations) are virtually identical. A Student's t-test of the means reveals no significant difference between the subject pools for any group.

Table 3.6 similarly compares four neck dimensions. All four are soft-tissue measures and, as indicated by observation of subjects, are quite dependent on weight and general body tone. Reference to the table reveals several significant differences between subject groups. This is particularly true among 35-44 year males, but may be easily explained by the composition of the category. Males (especially short males) in this group in the sagittal plane study tended to be overweight and "bull-necked." Most of those subjects did not participate in the lateral motion study, and the average neck dimensions reflect that. For these measurements, the sagittal plane study results are much larger on the average, though standard deviations remain similar.

Table 3.7 compares various body dimensions. Biacromial breadth and humeral biepicondylar diameter are bony-landmark measures; the biceps circumference and suprailiac skinfold are soft-tissue measures. Again, very similar results are noted between the two studies. However, significant differences at the 5% level occurred in several categories. In the case of biacromial breadth, the differences may be due to body build or the difficulty that many elderly subjects had in maintaining the necessary erect posture. The humeral biepicondylar diameter may differ because of technique, since a different instrument was used for this measure in the two studies. The greatest differences between the subject groups occur in the skinfold measure. Most of these differences are not found to be significant because of the large

Table 3.6

COMPARISON OF ANTHROPOMETRY RESULTS - MEAN VALUES OF SELECTED NECK MEASUREMENTS

		Age Groups in Years							
		18-24		35-44		62-74		Ages Combined	
		Lat.	Sag.	Lat.	Sag.	Lat.	Sag.	Lat.	Sag.
Females	N=	16	31	16	30	16	31	48	92
	Lat neck br.=	9.3**	9.8	9.3**	9.8	9.5*	10.0	9.4**	9.9
	Ant-post neck br.=	9.0	9.3	9.4	9.7	10.3	10.6	9.6	9.9
	Superior neck cir.=	32.8	32.2	33.1	32.6	35.9	35.6	33.9	33.5
	Inferior neck cir.=	36.2	35.8	35.4	35.8	38.0	37.1	36.5	36.3
Males	N=	17	30	15	30	16	27	48	87
	Lat neck br.=	11.0	11.4	10.8**	11.7	10.5	11.1	10.8**	11.4
	Ant-post neck br.=	10.6	10.9	11.1**	12.2	11.8*	12.6	11.1**	11.9
	Superior neck cir.=	37.2	36.9	40.3	41.2	41.4	41.4	39.6	39.8
	Inferior neck cir.=	40.6	40.8	41.5*	43.2	40.2	41.1	40.7	41.7
All Subjects Combined	N=							96	179
	Lat neck br.=							10.1**	10.6
	Ant-post neck br.=							10.4**	10.9
	Superior neck cir.=							36.8	36.5
	Inferior neck cir.=							38.6	38.9

All dimensions are in cm.

Note: ** denotes significant difference between means @ 1% level
* denotes significant difference between means @ 5% level

Table 3.7

COMPARISON OF ANTHROPOMETRY RESULTS - MEAN VALUES OF SELECTED BODY MEASUREMENTS

		Age Groups in Years							
		18-24		35-44		62-74		Ages Combined	
		Lat.	Sag.	Lat.	Sag.	Lat.	Sag.	Lat.	Sag.
Females	N=	16	31	16	30	16	31	48	92
	Biacromial br.=	34.7	35.5	35.0	35.7	34.6*	35.9	34.7*	35.7
	Biceps flx circum.=	26.8	27.2	28.4	28.6	30.9	31.0	28.7	28.9
	Suprailiac skinfold.=	10.4	13.5	11.5	13.1	18.3*	13.4	13.4	13.4
	Humeral dia.=	6.0*	6.5	6.0*	6.5	6.2	6.5	6.1*	6.5
Males	N=	17	30	15	30	16	27	48	87
	Biacromial br.=	39.6	39.9	39.0	39.7	37.1*	39.0	38.6	39.5
	Biceps flx cir.=	31.4	31.2	33.2	34.3	31.4	31.3	31.9	32.3
	Suprailiac skinfold=	9.5	12.9	15.2*	21.9	9.7*	13.6	11.3	16.2
	Humeral dia.=	7.0	7.0	7.1	7.1	7.0	6.9	7.1	7.0
All Subjects Combined	N=							96	179
	Biacromial br.=							36.6	37.6
	Biceps flx cir.=							30.3	30.6
	Suprailiac skinfold=							12.4	14.8
	Humeral dia.=							6.6*	6.8

Note: * denotes significant difference between means @ 5% level.

Suprailiac dimensions are in mm, all others are cm.

variance between subjects. This dimension is particularly sensitive to measurement technique and slight differences in weight or physical conditioning.

3. Location of Body Masses. Twenty-eight dimensions related to body mass were obtained from each subject. All of the results are contained in Appendix B, and two sets of measures are summarized here for illustrative purposes.

Table 3.8 summarizes the data obtained for the upper torso and upper leg segments. The upper torso is represented by chest height, breadth, and circumference. The chest height dimensions tend to duplicate stature trends for the various subject groups, and, in fact, chest height averages 75% of stature for each subject group. Upper torso mass (as represented by chest breadth and circumference) remains relatively constant throughout life for males, but tends to increase with age in females. On the average, males are larger than females in both dimensions.

The upper leg is represented by the trochanterion-femoral condyle length and the upper and lower thigh circumferences. Table 3.8 shows that the average trochanterion-femoral condyle length is approximately 42 centimeters for all subject groups, even though overall body stature tends to decrease with age. Although males are much taller, on the average, than females, male upper leg length averages only one centimeter greater than females. Appendix B reports a 12-cm range of lengths throughout the sample, but the averages for each group are surprisingly similar. Upper and lower thigh circumferences are similar for sexes of the same age, except that elderly females are much larger in the upper

Table 3.8

SELECTED RESULTS - LOCATION OF MAJOR BODY MASSES

		Age Group in Years							
		18-24		35-44		62-74		AGES COMBINED	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
FEMALES	Chest:								
	Ht.	121.8	3.7	122.8	4.5	117.9	5.1	120.8	4.9
	Br.	26.0	1.9	27.6	2.1	28.8	2.8	27.5	2.5
	Cir.	83.3	4.0	85.8	5.6	90.7	6.7	86.5	6.2
	TRCFEM:	41.9	2.5	41.7	2.4	42.2	2.3	41.9	2.4
	UPRTHI:	57.3	3.9	58.1	5.2	61.5	7.7	58.9	5.9
	LWRTHI:	37.6	2.9	37.6	3.2	39.9	4.6	38.4	3.7
MALES	Chest:								
	Ht.	131.3	3.8	131.3	5.6	127.8	4.1	130.1	4.7
	Br.	31.4	2.6	32.0	1.6	31.2	2.7	31.5	2.3
	Cir.	94.9	5.3	101.0	4.8	96.1	4.9	97.2	5.6
	TRCFEM:	42.5	2.3	42.2	2.6	42.2	2.3	42.9	2.5
	UPRTHI:	56.6	6.3	58.5	4.6	53.6	3.2	56.2	5.2
	LWRTHI:	38.6	3.1	40.1	1.7	37.5	2.7	38.7	2.8
ALL SUBJECTS COMBINED	Chest:								
	Ht.							125.5	6.7
	Br.							29.6	3.1
	Cir.							91.8	7.9
	TRCFEM:							42.4	2.5
	UPRTHI:							57.5	5.7
	LWRTHI:							38.5	3.3

code: TRCFEM - Trocanter-femoral condyle length (upper leg)
UPRTHI - Upper thigh circumference
LWRTHI - Lower thigh circumference

all dimensions are in centimeters

thigh region than elderly males.

4. Description of the Seated Occupant. Thirty-two measurements were used to describe the seated occupant with reference to a three-dimensional coordinate system. Twenty-one measures were taken to locate certain landmarks on the head, upper torso, and pelvis; eleven are reported which locate certain landmarks with respect to certain other landmarks, particularly on the head. Descriptive statistics for these measures are reported in Appendix B, together with statistics for 24 others which specify head and upper torso locations with respect to the SRP only and permit calculations relating one landmark to another.

Using the results tabulated in Appendix B, six illustrations were prepared, one for each of the six combinations of sex and age. The illustrations depict the "average" person in each subject category, positioned in the unpadded simulated auto seat. Front and side views are used to show the occupant in three dimensions. The mean value of each measurement was plotted to make the illustration.

These six illustrations of seated occupants are as follows:

Figure 3.1--Average Female, 18-24 years

Figure 3.2--Average Female, 35-44 years

Figure 3.3--Average Female, 62-74 years

Figure 3.4--Average Male, 18-24 years

Figure 3.5--Average Male, 35-44 years

Figure 3.6--Average Male, 62-74 years.

A total of 38 measurements in each category were plotted for the illustration, as indicated below.

Normal sitting height.

Head: Tragion height and depth, bitragion diameter, glabella height and depth (assumed to be on mid-sagittal plane), eyellipse point height, depth and width, head breadth and length, sagittal and coronal arcs, facial height. Also indicated are bitragion-glabella, bitragion-menton, and bitragion-inion arc lengths.

Torso and Pelvis: Cervicale height and depth, suprasternale height and depth (cervicale and suprasternale assumed to be in mid-sagittal plane), shoulder height, depth and breadth, anterior superior iliac spine height and depth, bispinous breadth.

Extremities: Acromion-radiale length, radiale-stylion length, hand length; trochanterion height and depth, bitrochanterion diameter, trochanterion-femoral condyle length, fibula length, fibula height, foot length and breadth.

Note that arms and legs are positioned arbitrarily for illustrative purposes. The arms are shown with upper arms vertical and with the elbow flexed 90°. The femur segment is drawn parallel to the seat pan surface with the lower legs vertical; the chair height and floor are not depicted. Note also, in the front view, that the most lateral surface of the arms and legs is shown, rather than the centerline. The measurements were obtained in this manner and no correction factor to locate the centerline of the limb has been assumed.

While Figures 3.1 through 3.6 are illustrative of the six subject categories, it is difficult to make comparisons of landmark locations

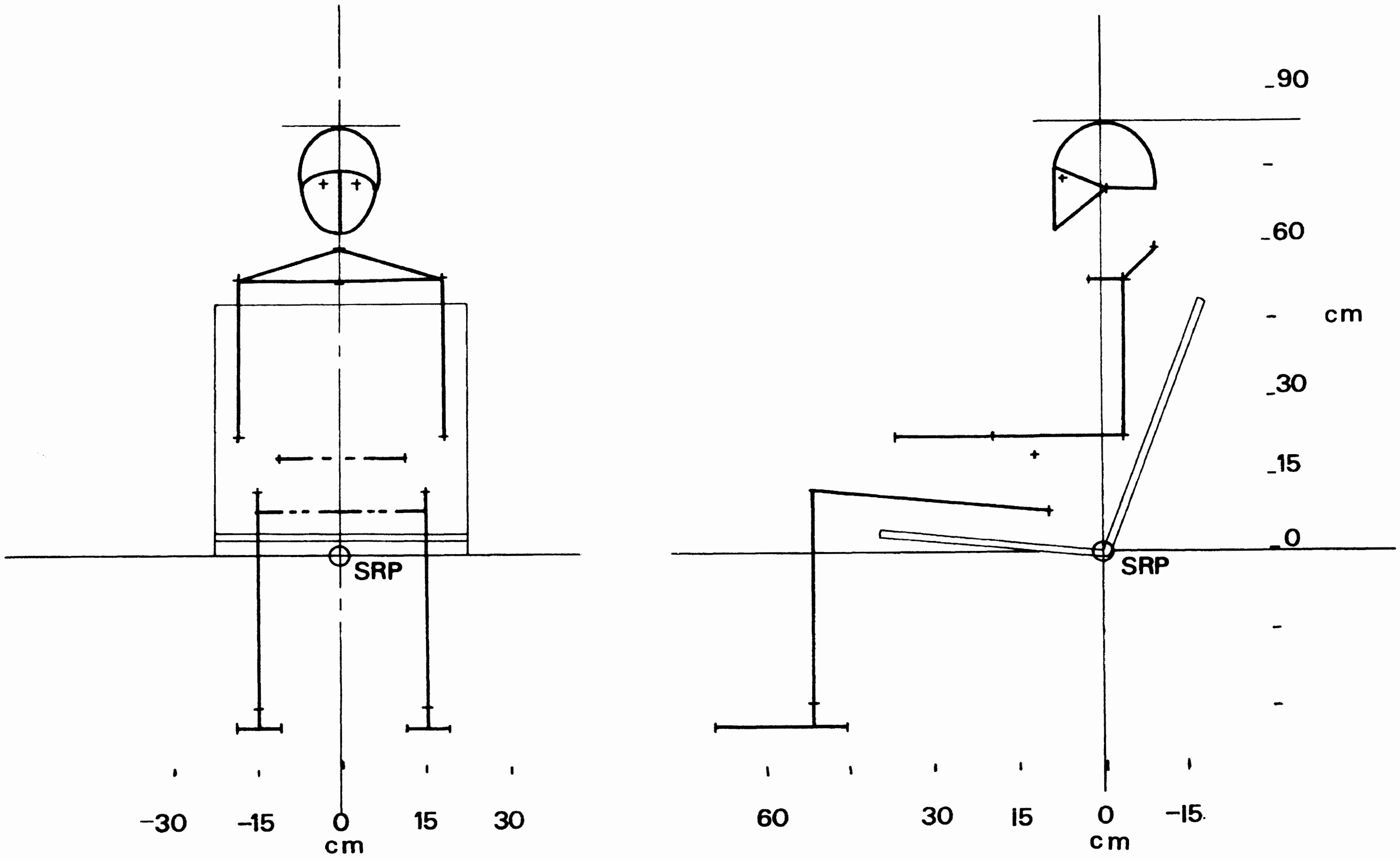


Figure 3.1 Seated position of "average" female, age 18-24 years.

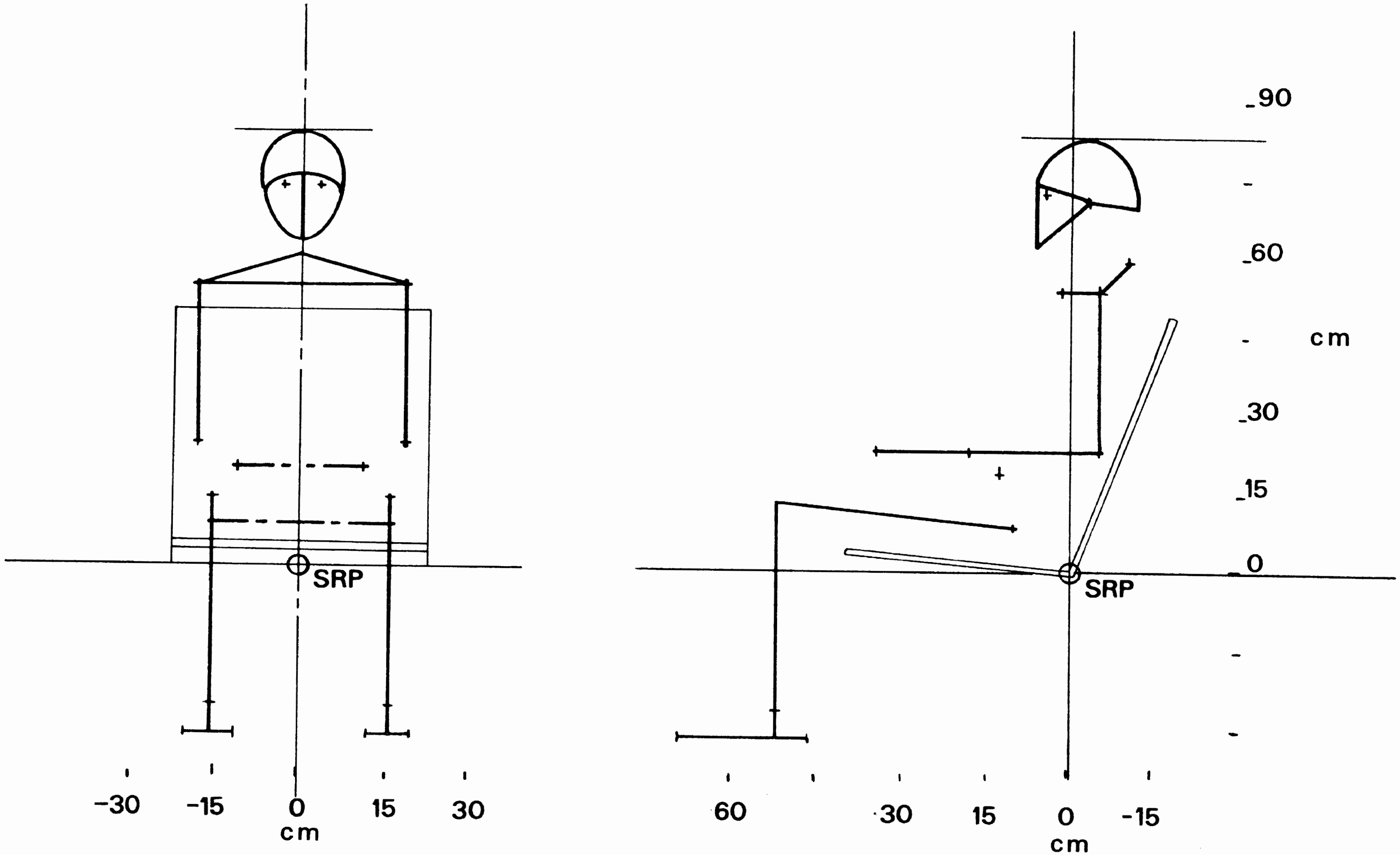


Figure 3.2 Seated position of "average" female, age 35-44 years.

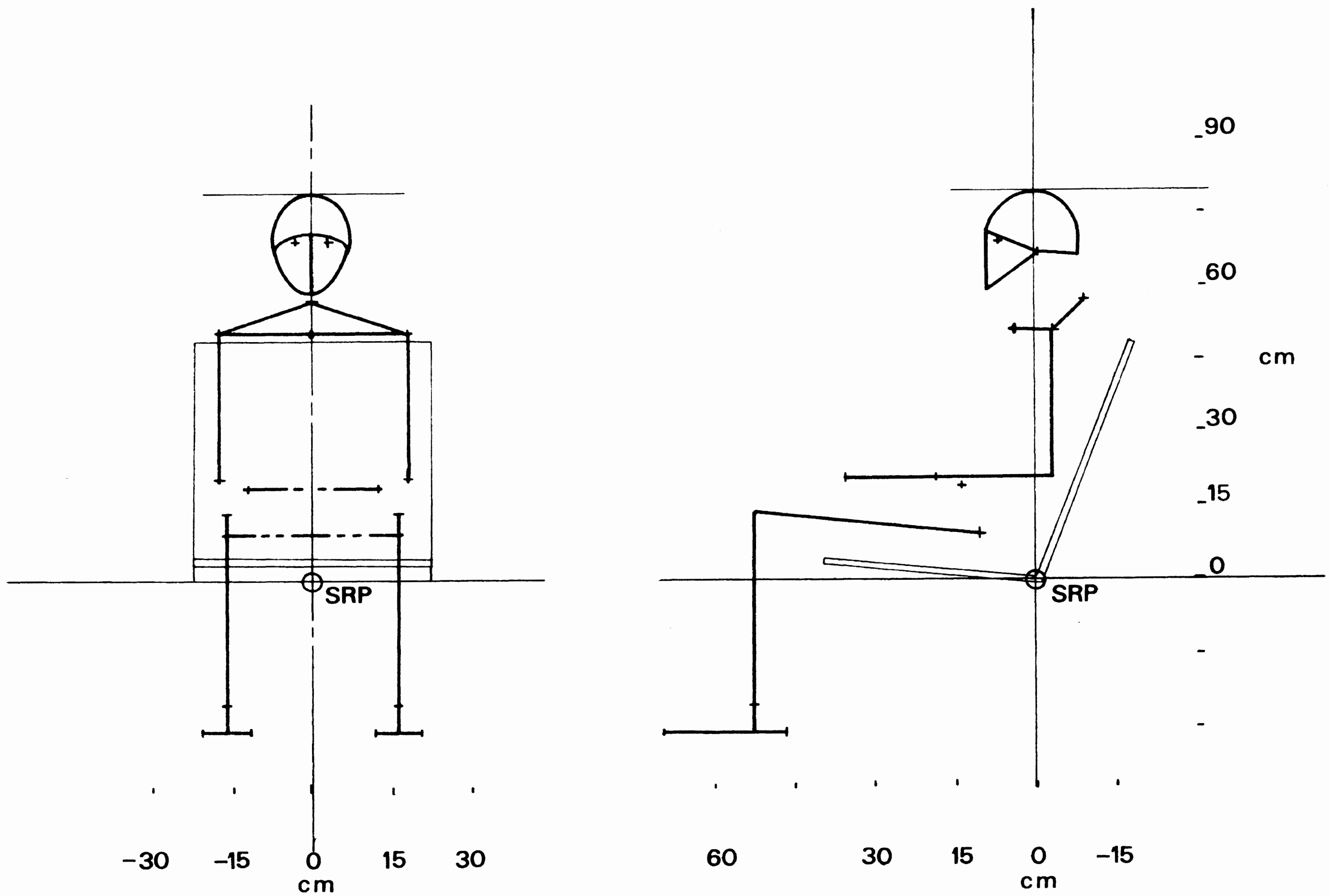


Figure 3.3 Seated position of "average" female, age 62-74 years.

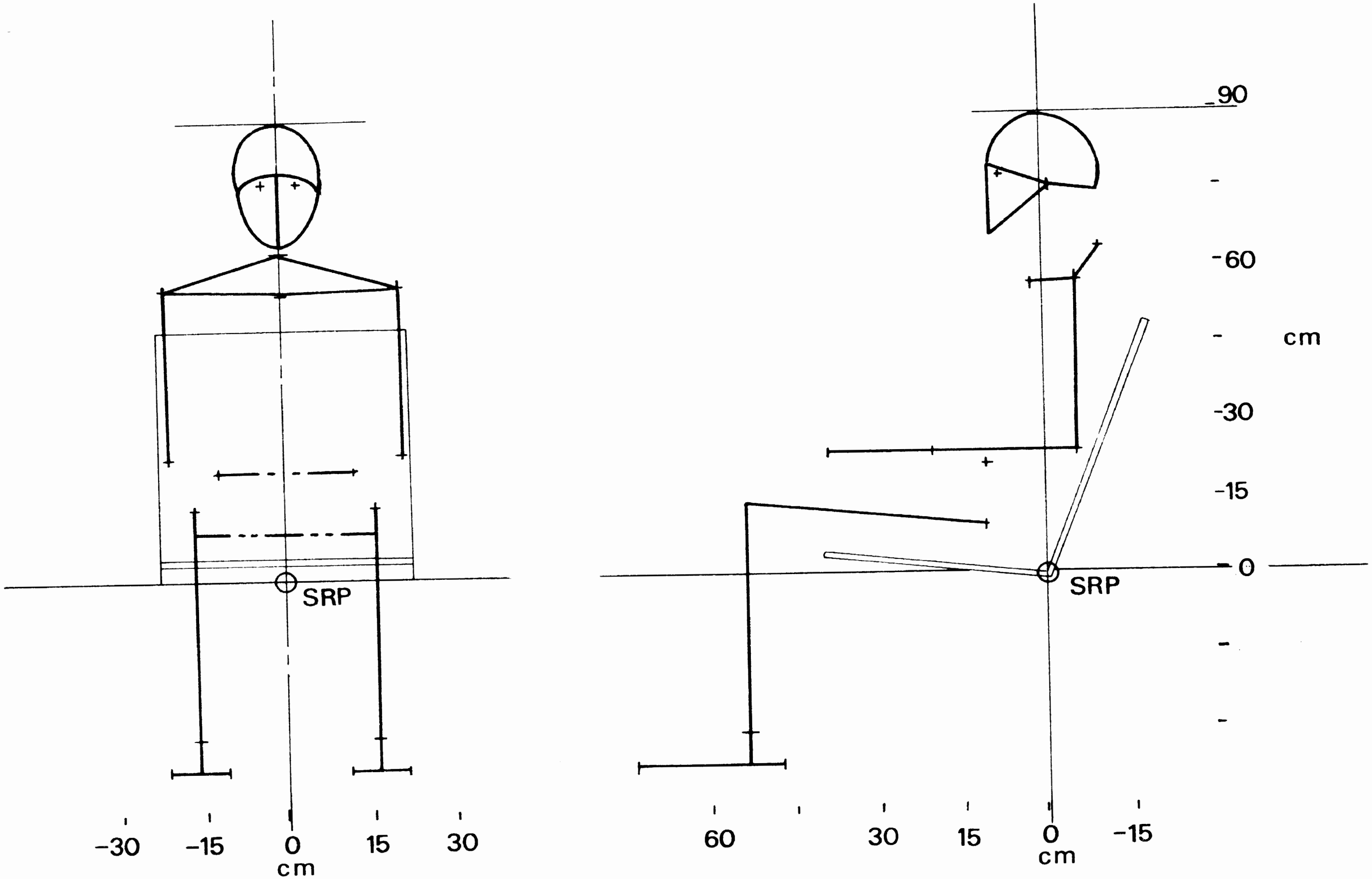


Figure 3.4 Seated position of "average" male, age 18-24 years.

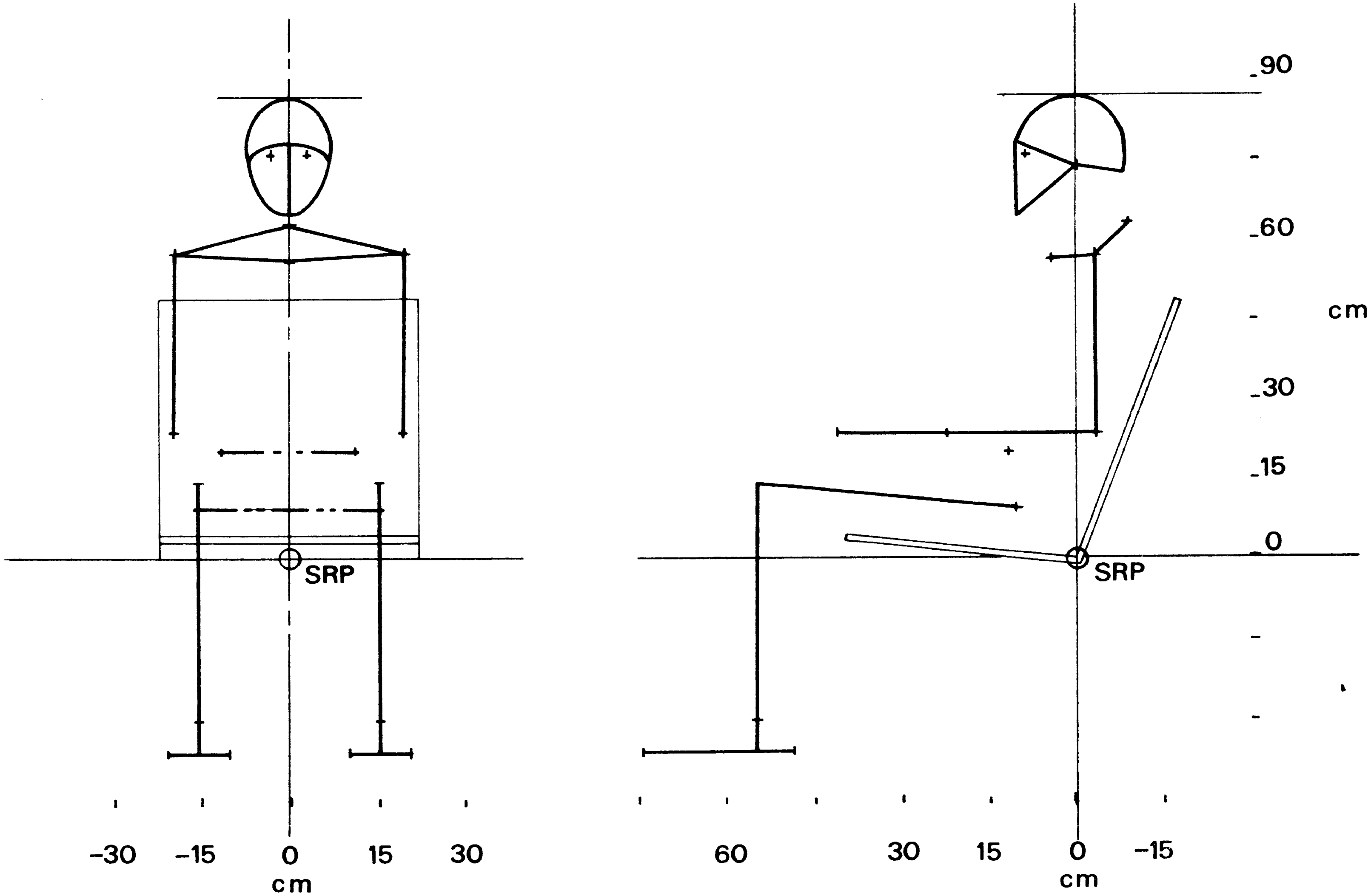


Figure 3.5 Seated position of "average" male, age 35-44 years.

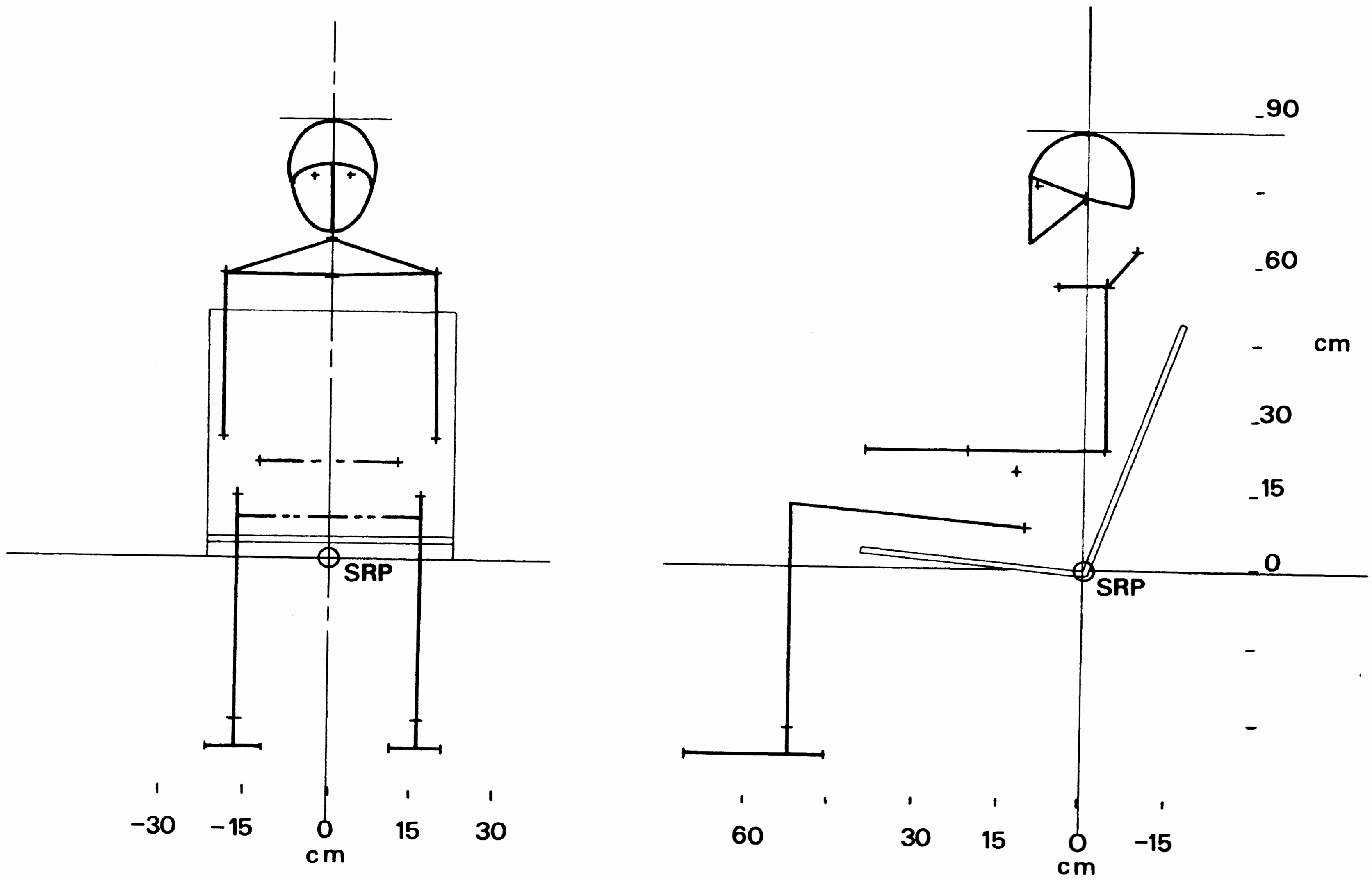


Figure 3.6 Seated position of "average" male, age 62-74 years.

for different subject groups without placing one figure over another. For that reason, Figure 3.7 was compiled. Figure 3.7 is a plot of the mean value of each of the designated body landmarks for each of the subject categories. These points were obtained directly from Figures 3.1 through 3.6, but no attempt is made to differentiate between subject categories. Figure 3.7 points up the rather large variation in torso and head landmarks to be found in the population, even when only average values are compared. It also illustrates the narrow range of variation in the lower body, since trochanterion, anterior superior iliac spine (ASIS), and femoral condyle locations are all closely grouped.

It was mentioned in Chapter 2 that seated position locations for the eye have been described for automotive design purposes. The most-recently-published results from an auto industry source were consulted in an effort to compare them to the results from this study. Roe (1975) has published eye and top-of-head locations obtained from 120 male and female subjects sitting in automobile seats in three standard SAE seating fixtures. Head and eye locations were specified relative to the "H-Point", a standard SAE seating-design reference that is intended to be representative of the hip joint center. In order to compare the SAE results with those of the lateral motion study, it was necessary to locate the H-Point with respect to the Seat Reference Point of the unpadded chair. Robbins and Reynolds (1975) recently reported the H-Point location, for the same type of seat as that used in the lateral motion study, to be 9.75 cm above the SRP. This dimension was subtracted from the average values of normal sitting height and eyellipse height. The resulting values are compared to the SAE data in Table 3.9. The SAE Fixture II (seat back angle 23.5°) and SAE

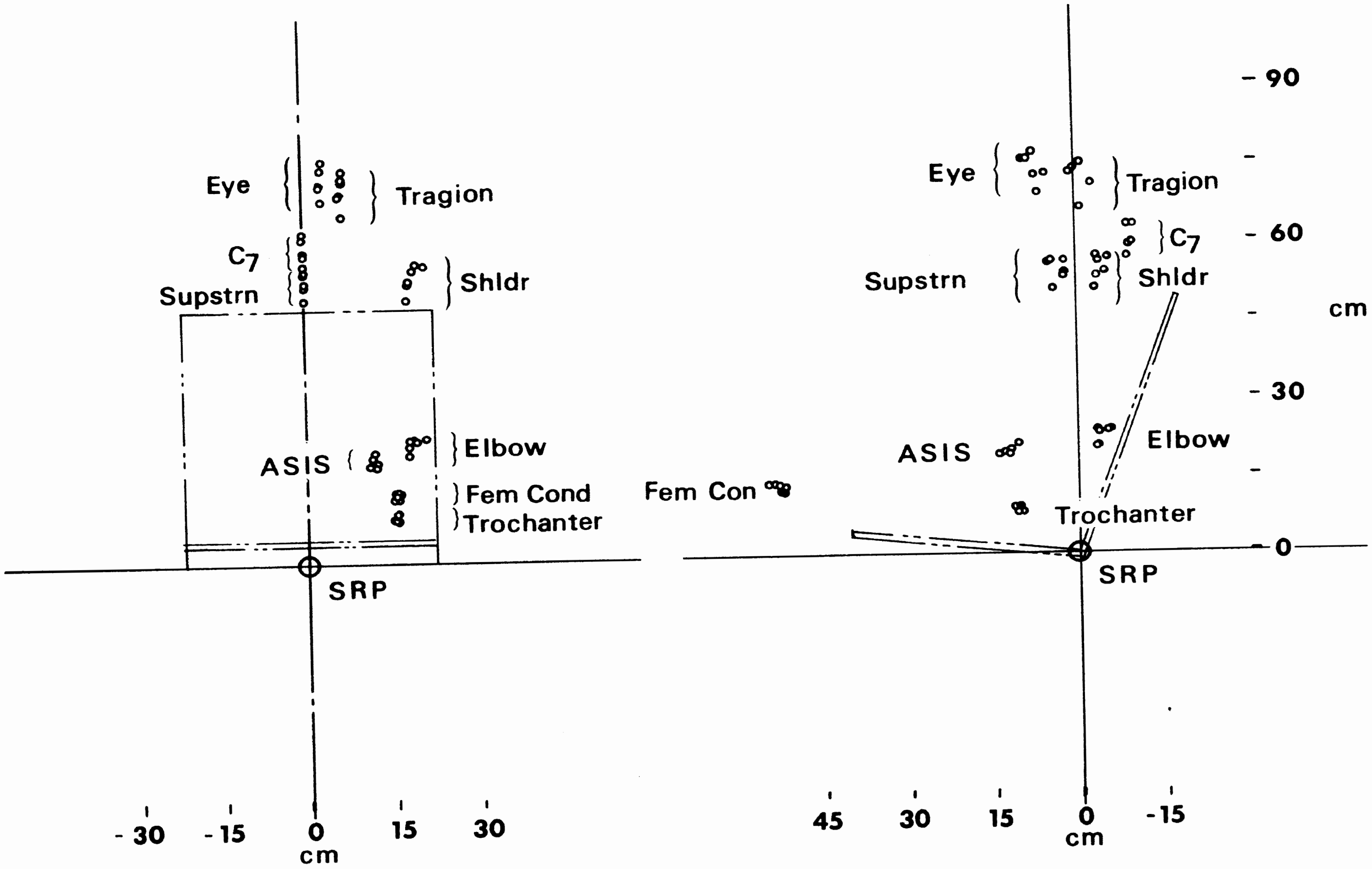


Figure 3.7 Seated-position locations of eight body landmarks for six subject categories.

Table 3.9

HEAD AND EYE LOCATIONS FOR THE SEATED OCCUPANT - COMPARISONS WITH AUTO INDUSTRY STUDIES [1]

	H-Point[2] to Top of Head, cm.			H-Point to Eye-ellipse Point[3], cm.		
	F[4]	M	F+M	F	M	F+M
LATERAL MOTION STUDY[5]	72.4	77.8	75.0	61.9	66.8	64.4
SAE- FIXTURE I[6]	71.6	73.8	72.7	57.7	62.1	59.9
SAE- FIXTURE II	75.1	76.3	75.7	60.7	64.2	62.4
SAE- FIXTURE III	76.2	77.5	77.0	61.4	65.1	63.3
SAE- COMPOSITE[7]	N.D.	N.D.	74.4	N.D.	N.D.	61.7

Notes: (1) SAE results as published by Roe (1975).

(2) SAE standard H-Point location determined for Lateral Motion Study SRP as described by Robbins and Reynolds (1975). H-Point is 0.85 cm. above average trocanter height.

(3) Eyellipse point is mean of z-distance for lateral study, centroid of constructed "eyellipse" for SAE.

(4) Subject pool sizes:

Lateral Motion Study - 96 (48 females, 48 males)

SAE Study - 120 (60 females, 60 males)

Each subject pool stratified by sex, age, and stature.

(5) Seat used was unpadded, simulated auto seat with seat back angle of 25 degrees.

(6) SAE Fixtures have padded auto seats:

Fixture I (sports car), seat back angle of 29.5^o

Fixture II (light truck), seat back angle of 23.5^o

Fixture III (heavy truck), seat back angle of 15.7^o

(7) Composite is combined results from seating studies with 3 SAE Fixtures, 3 standard-size automobiles, and van trucks. All data were adjusted to a 25^o seat back angle.

composite (data adjusted to seat back angle of 25°) should be the most comparable to lateral motion study results (seat back angle 25°). The H-Point to top-of-head results are comparable for men and women combined, but the lateral motion study results are in marked disagreement with the SAE results for eye location. The probable source of difference is in the method by which the SAE "eyellipse" is constructed. It is a so-called "tangent cutoff ellipse," and has the effect of locating the centroid of the ellipse some distance below the actual mean Z-distance of the subject data. It is not possible to compare the SAE and lateral data directly, since the SAE raw data are not available. Other differences which tend to produce unknown variability include seat compression effects from soft seats that may not appear in hard seat data, and head position effects (lateral motion subjects are positioned with head in Frankfort Plane neutral position, SAE subjects are not).

5. Anthropometry Correlations. An intercorrelation matrix was prepared so that correlations between various anthropometric measures could be investigated. High correlations between measures provide some degree of confidence that one measurement can be predicted based on another and perhaps easier-to-obtain measure. Some of the most significant correlations that were found are summarized in Table 3.10. Only correlation coefficients greater than .707 are reported (r = .707 indicates that 50% of the variance between the two measures is explained by their inter-relationship). Table 3.10 is a partial matrix of representative measures; several others (such as foot length, bideltoid breadth, etc.) also had high correlations with other measures. They are not contained in the table because they tended to

Table 3.10

PARTIAL INTERCORRELATION MATRIX FOR ANTHROPOMETRY
selected correlations for which r > .707
(Based on data for all subjects combined)

	Wt.	Stat.	Erect Sit. Ht.	Norm. Sit. Ht. re SRP	Lat. Neck Br.	Sup. Neck Cir.	Biacr. Br.	Chest Ht.	Chest Br.	Chest Cir.	Acrom. Rad. Len.	Arm Cir.@ Axilla	Biceps Flexed Cir.	Rad. Styl. Len.	Fibula Ht.	Trag. Ht. re SRP
Erect Sitting Ht.		.91	-					.86						.72	.74	.96
Normal Sitting Ht.		.89	.96	-				.84						.71	.72	.95
Ant-Post. Neck Br.	.71				.71	.92				.79						
Inferior Neck Cir.	.76				.84	.83	.71			.80			.72			
Biacromial Br.		.74			.80		-									
Chest Ht.		.96	.86	.84				-			.76			.83	.89	.85
Chest Br.	.75				.71					.79		.71				
Chest Cir.	.87				.80	.82			.79	-		.84	.84			
Waist Ht.		.82	.72					.78						.73	.77	
Waist Br.	.79					.71			.72	.78		.73	.71			
Waist Cir.	.82					.85				.84		.79	.78			
Hip Ht.		.86	.71					.83			.75			.80	.86	
Hip Br.(stdg)																
Hip Cir.	.73															
Acrom-Radiale Length		.81						.76			-			.80	.81	
Arm Cir. @ Axilla	.88					.73			.71	.84		-	.94			
Biceps Flexed Cir.	.88					.74				.84		.94	-			
Radiale-Stylion Length		.88	.72	.71			.72	.83			.80			-	.87	
Forearm Cir.	.84				.83	.76	.71			.85		.82	.85			
Fibula Ht.		.91	.74	.72				.89			.81			.87	-	.71
Tragion Ht. (re SRP)		.88	.95	.95				.85							.71	-
Eye Point Ht. (re SRP)		.89	.95	.96				.85							.73	.99
Cervicale Ht. (re SRP)		.84	.90	.90				.81								.94
Suprastern. Ht. (re SRP)		.79	.86	.89				.79								.93
Shoulder Ht. (re SRP)		.79	.85	.86				.78								.87
Shoulder Breadth		.76			.76		.85									

duplicate the correlation pattern of measures that are included.

Examination of Table 3.10 shows that the most correlations, and often the highest, occurred with measurements that are most routinely obtained: weight, stature, erect and normal sitting height. Two other stature-related dimensions--chest height (standing) and tragion height (sitting)--were correlated with many other dimensions. Neck breadths and circumferences were often correlated with breadths and circumferences elsewhere on the body. In general, body element heights and lengths are highly correlated with stature. Body element breadths and circumferences are similarly correlated with weight. These results support the generally accepted hypothesis that lengths are stature-related and circumferences are weight-related and therefore should be considered separately. Weight and stature are not correlated (r = .56).

6. Summary. The basic results of the anthropometric study have been reported in this chapter and in Appendix B. Many more results are available by combinations of the reported data: Heath-Carter somatotypes, interrelationships of various body landmarks, body proportions, mass locations of standing persons, etc., may all be derived from these data. Limited space in this report does not allow further development of results, but it is hoped that other investigators may find the published tabular data useful in developing their own applications.

C. Range of Motion

Appendix C gives the complete list of Euler angle statistics obtained from photogrammetry analysis of voluntary head movements for the various groups of subjects. Tables 3.11 through 3.21 and Figures

3.8 through 3.11 have been extracted from these data to present the primary results in a more readable form. It should be remembered that the sign convention for the Euler angles is for a right-handed coordinate system with the positive z-axis down and the positive y-axis pointing to the subject's right side. This is different from the axis system shown in Figure 2.24 which was used in the photogrammetry calculations for anthropometry. The result is to reverse the sign of the pitch and roll Euler angles. This was done to make the Euler angles correspond to the usual conventions used in computer modeling. For this system, then, right rotation, extension, and right lateral bend are positive, while left rotation, flexion, and left lateral bend are negative.

Table 3.11 presents the total planar ranges of motion in the sagittal, rotational, and lateral planes for the various subject groups and for all males, all females, and all subjects. For each plane, the ranges of motion for males and females are nearly the same but decrease with age, as is more clearly illustrated by Figures 3.8 through 3.10. Figure 3.11 illustrates this decrease with age for males and females combined. The largest range of motion is in rotation, while the smallest is in lateral bend for all age groups, and the rate of decrease with age appears to be similar for each. As Figures 3.8 through 3.10 show, however, males tend to show a slightly sharper decrease with age than females. Table 3.12 shows the percentage decrease from young to elderly age groups, for range of motion in the three planes, for males and females separately.

Table 3.11

TOTAL PLANAR RANGE OF MOTION BY SUBJECT GROUP

SUBJECT GROUP	TOTAL PLANAR RANGE OF MOTION		
	SAGITTAL	ROTATION	LATERAL
FEMALE,18-24	124.1	150.6	86.0
FEMALE,35-44	104.6	143.6	73.9
FEMALE,62-74	84.3	123.6	56.3
MALE,18-24	129.0	149.5	86.3
MALE,35-44	102.7	137.1	73.0
MALE,62-74	76.6	113.9	48.0
FEMALE	104.2	139.3	72.0
MALE	103.3	133.7	69.8
ALL SUBJ'S.	103.7	136.5	71.0

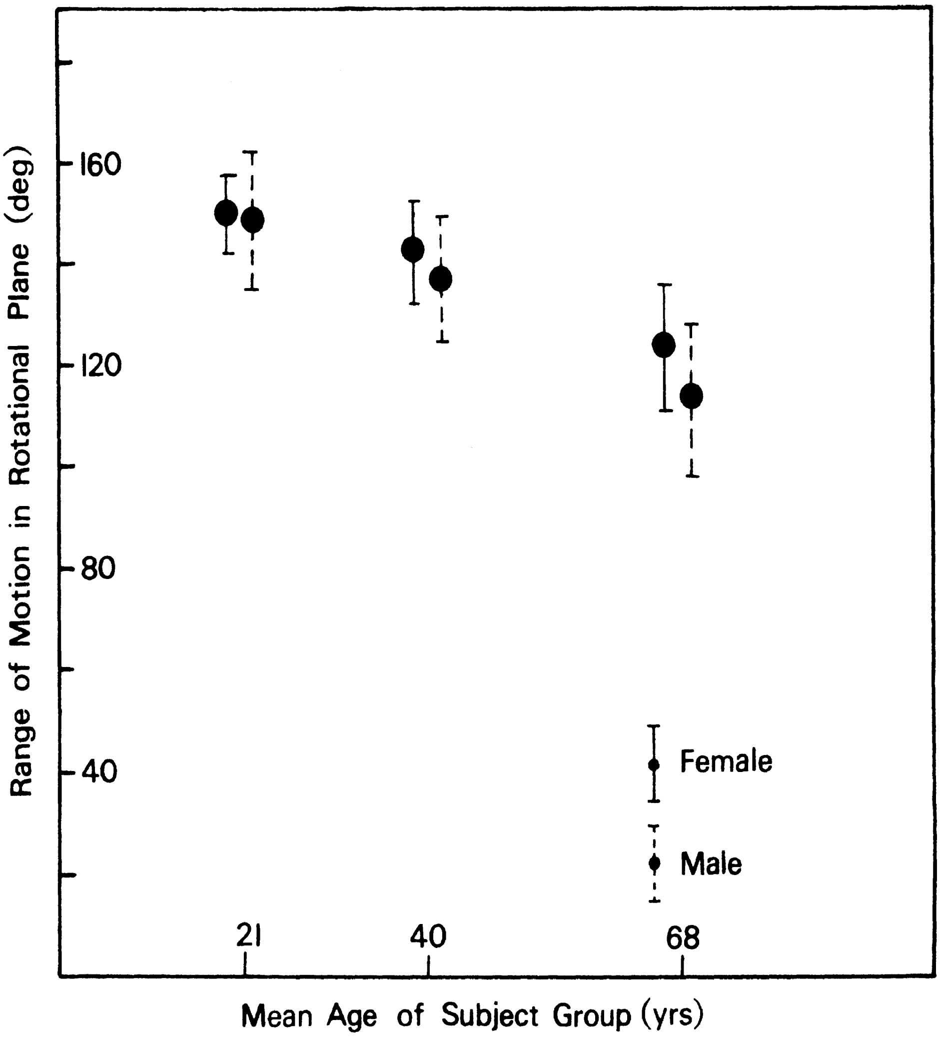


Figure 3.8 Range of motion in rotational plane versus mean age of subject group. Brackets indicate the standard deviation of the sample.

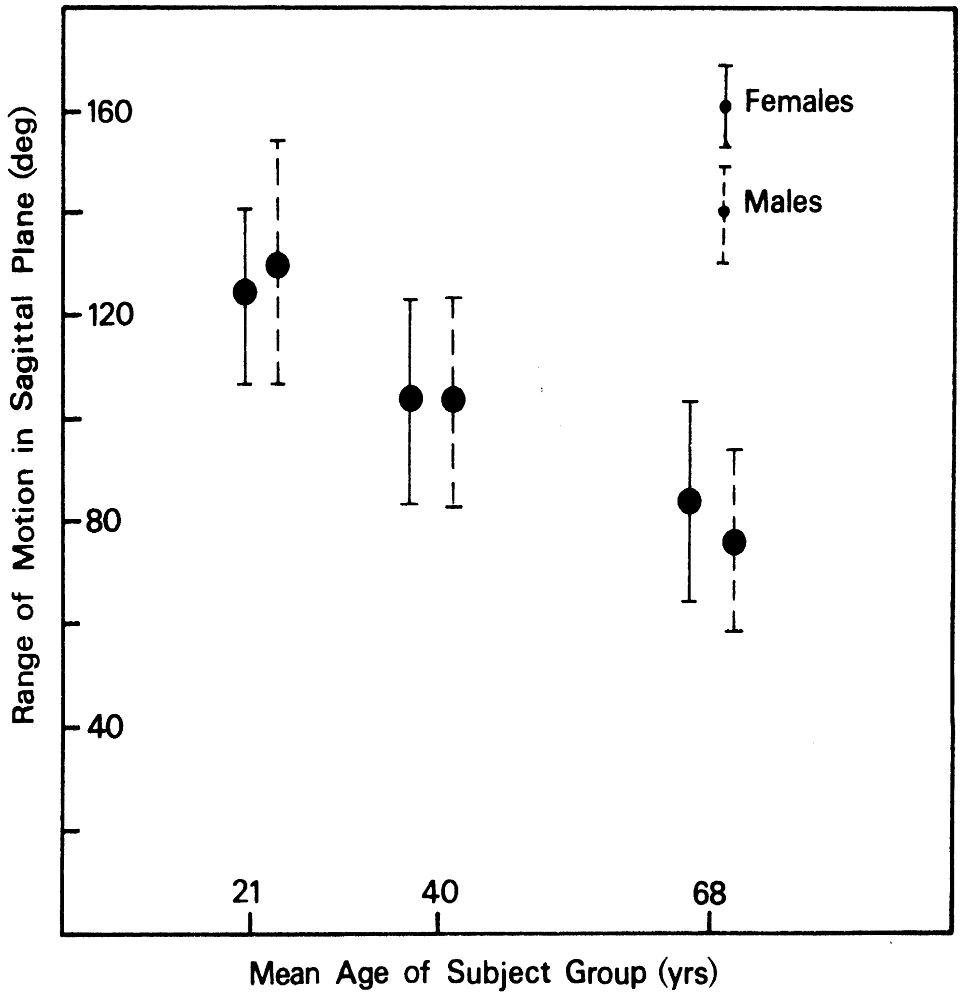


Figure 3.9 Range of motion in sagittal plane versus mean age of subject group. Brackets indicate the standard deviation of the sample.

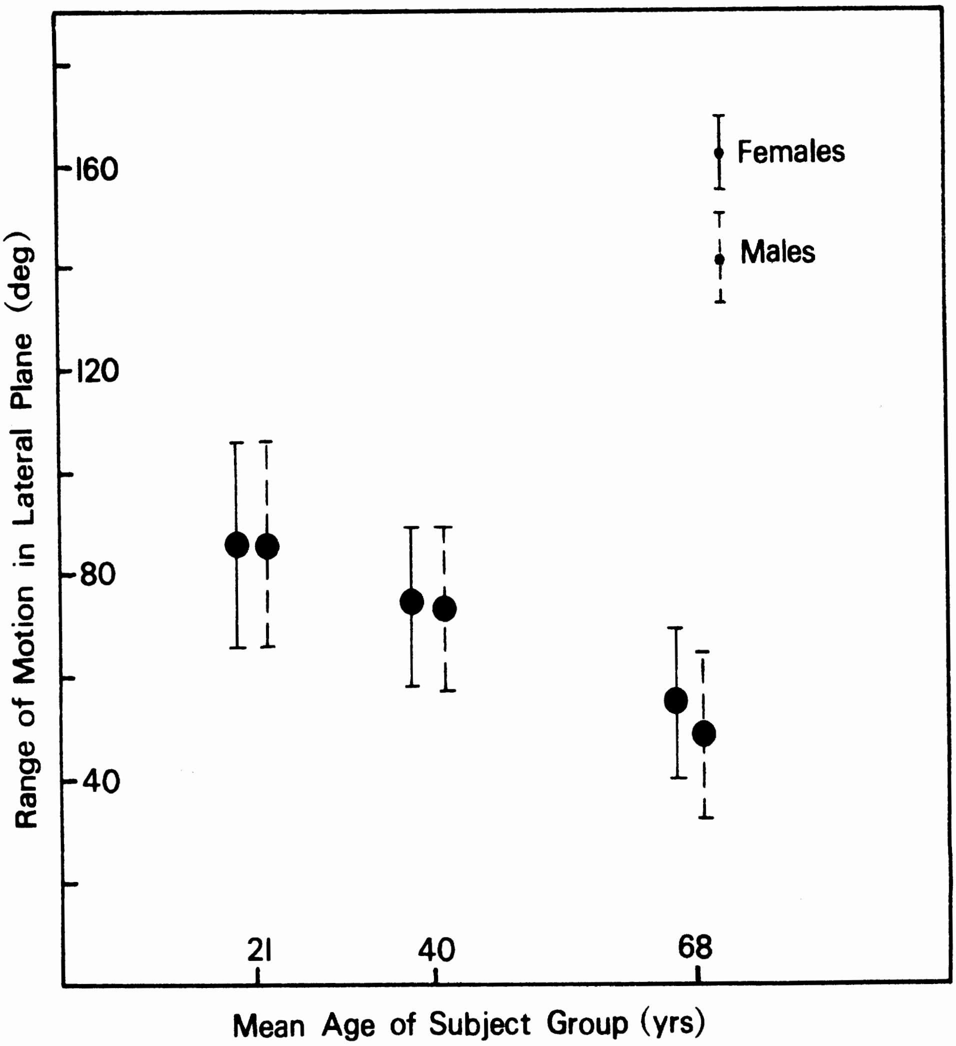


Figure 3.10 Range of motion in lateral plane versus mean age of subject group. Brackets indicate the standard deviation of the sample.

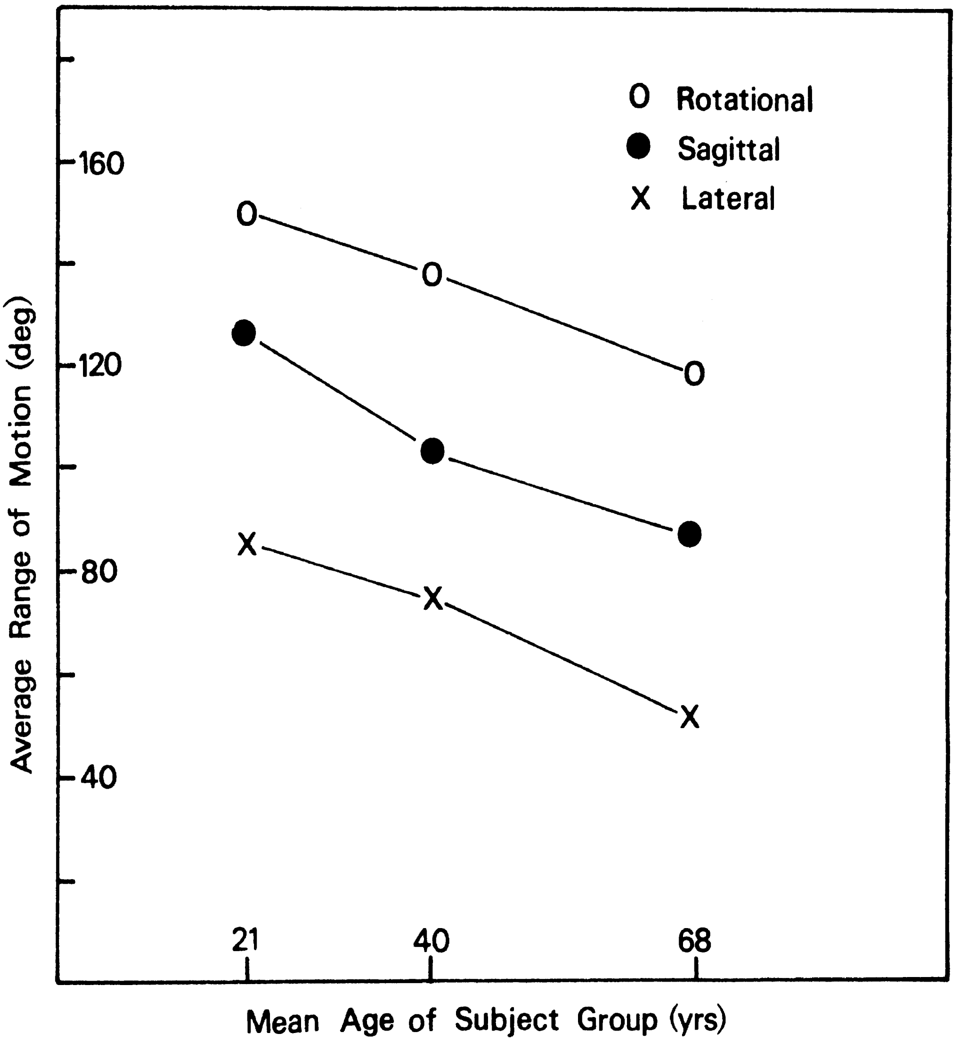


Figure 3.11 Average range of motion versus mean age of subject group for males and females combined.

Table 3.12

Percentage Decrease in Total Range of Motion between Young and Elderly Age Groups

	Sagittal	Rotational	Lateral
Females	32.1	17.9	34.5
Males	40.6	23.8	44.4

Tables 3.13, 3.14, and 3.15 show the average Euler angles at each of the test positions for all subjects, females and males, respectively. Again it is seen that there is little overall difference in results between males and females. Several other observations which can be made by simple inspection of these tables and tables 3.16 through 3.21 for all other subject groups are:

1) The amount of flexion possible after rotation is about half that possible from the Frankfort Plane position.

2) The amount of lateral bend possible after full rotation is nearly the same as that possible from the Frankfort Plane position.

3) The amount of extension possible after full rotation was about one-third that possible from the Frankfort Plane position, was relatively independent of age, and was usually accompanied by some right lateral bend.

4) Full right rotation was usually accompanied by a slight right lateral bend, while full left rotation was usually accompanied

Table 3.13

EULER ANGLES FOR ALL SUBJECTS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	-.4	-1.3	-1.1
EXTENSION	.6	54.2	-.8
FLEXION	1.9	-49.5	-4.5
RROT.	67.5	-1.1	4.3
LROT.	-69.0	-2.1	-9.8
RLB	2.9	1.8	32.5
LLB	-6.1	2.2	-38.3
LROT+FLX	-67.2	-24.6	-14.1
LROT+LLB	-68.1	7.9	-37.8
RROT+EXT	64.5	18.4	7.0

Table 3.14

EULER ANGLES FOR ALL FEMALES

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	.73	-.5	-1.4
EXTENSION	.7	53.6	-1.4
FLEXION	1.1	-50.5	-5.0
RROT.	68.5	-.2	5.4
LROT.	-70.8	-1.9	-12.7
RLB	1.7	2.5	31.7
LLB	-5.0	2.2	-40.3
LROT+FLX	-67.9	-25.3	-16.5
LROT+LLB	-69.7	5.9	-40.3
RROT+EXT	66.4	19.0	9.2

Table 3.15

EULER ANGLES FOR ALL MALES

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	-.2	-2.2	-.8
EXTENSION	1.1	54.7	-.5
FLEXION	2.8	-48.6	-4.0
RROT.	66.4	-2.1	3.4
LROT.	-67.3	-2.3	-7.0
RLB	4.1	1.2	33.3
LLB	-6.2	2.2	-36.3
LROT+FLX	-66.5	-24.0	-11.8
LROT+LLB	-66.5	9.8	-35.3
RROT+EXT	62.6	17.9	4.8

Table 3.16

EULER ANGLES FOR FEMALES, 18-24 YRS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	.4	.2	-1.0
EXTENSION	.5	64.7	-.5
FLEXION	.8	-59.3	-3.7
RROT.	74.1	-.5	5.1
LROT.	-76.5	-1.9	-9.1
RLB	1.1	-.8	40.4
LLB	-5.1	.9	-45.6
LROT+FLX	-74.7	-30.3	-13.6
LROT+LLB	-73.7	4.0	-40.0
RROT+EXT	70.1	22.0	7.3

Table 3.17

EULER ANGLES FOR FEMALES, 35-44 YRS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	.9	-1.8	-1.1
EXTENSION	.6	52.7	-.3
FLEXION	2.6	-51.5	-5.4
RROT.	71.6	-.5	4.1
LROT.	-72.0	-3.7	-12.9
RLB	1.3	2.6	31.6
LLB	-3.8	3.2	-42.2
LROT+FLX	-70.1	-25.5	-17.4
LROT+LLB	-73.5	6.9	-45.4
RROT+EXT	72.1	17.7	10.1

Table 3.18

EULER ANGLES FOR FEMALES, 62-74 YRS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	-.3	.4	-1.9
EXTENSION	-.6	43.5	-2.4
FLEXION	-.8	-40.7	-5.6
RROT.	59.7	.5	6.9
LROT.	-63.8	-.4	-16.0
RLB	2.8	5.6	23.1
LLB	-8.9	2.4	-33.1
LROT+FLX	-59.5	-20.5	-18.2
LROT+LLB	-62.6	6.67	-36.8
RROT+EXT	56.9	17.3	10.1

Table 3.19

EULER ANGLES FOR MALES, 18-24 YRS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	-.5	-1.7	-.5
EXTENSION	-.5	72.8	-2.3
FLEXION	3.3	-56.2	-3.4
RROT.	73.2	-2.4	4.2
LROT.	-76.2	-3.2	-6.4
RLB	1.3	.28	41.7
LLB	-4.3	3.4	-44.6
LROT+FLX	-73.2	-26.7	-9.6
LROT+LLB	-74.5	9.8	-41.4
RROT+EXT	68.7	17.4	4.9

Table 3.20

EULER ANGLES FOR MALES, 35-44 YRS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	.1	-2.1	-.8
EXTENSION	3.1	52.2	-.6
FLEXION	2.3	-50.5	-3.0
RROT.	68.5	-2.5	3.3
LROT.	-68.6	-2.9	-7.7
RLB	6.9	-.4	34.8
LLB	-8.3	.2	-38.2
LROT+FLX	-68.4	-24.3	-13.6
LROT+LLB	-65.7	9.3	-37.0
RROT+EXT	64.3	19.1	4.5

Table 3.21

EULER ANGLES FOR MALES, 62-74 YRS

POSITION	EULER ANGLES RE FRANKFORT POSITION		
	YAW	PITCH	ROLL
NEUTRAL	.6	-2.8	-1.3
EXTENSION	.2	37.8	.9
FLEXION	2.6	-38.8	-5.4
RROT.	57.3	-1.4	2.5
LROT.	-56.5	-.8	-7.1
RLB	4.3	3.6	22.2
LLB	-6.3	2.9	-25.8
LROT+FLX	-57.6	-20.6	-12.5
LROT+LLB	-58.1	10.5	-28.1
RROT+EXT	54.9	17.2	5.0

by a slight left lateral bend.

5) The average subject neutral position was nearly identical to that of the Frankfort Plane position.

6) The amount of extension possible from the Frankfort Plane position was usually greater than the amount of flexion, especially in the 18 to 24-year-old groups.

7) The amount of left lateral bend was usually greater than the amount of right lateral bend, although it was accompanied by a greater amount of head rotation.

D. Reflex Time

Table 3.22 and Figure 3.12 present the results of the reflex time analysis for the right sternomastoid muscle group resulting from lateral head jerks to the left. For females, the reflex time is nearly the same for the young and middle aged groups (45.1 msec. and 43.6 msec., respectively), but shows a significant increase to 53 msec. for elderly females. For the males, the reflex time shows a steady increase with age and for each group is greater than the average reflex time for the respective female group. This difference in reflex times between the sexes is most pronounced for the middle age groups, where the average for females was 43.6 msec. compared to that for the males of 52.8 msec. The average reflex time for all males was 53.3 msec., compared to 47.1 msec. for all females, and the overall average for all subjects (N=94) was 50.2 msec.

Table 3.23 shows a comparison of reflex times obtained in the

Table 3.22

REFLEX TIMES OF RIGHT STERNOMASTOID MUSCLE GROUP IN LATERAL BEND

		AGE GROUP IN YEARS			
		18 - 24	35 - 44	62 - 74	COMBINED AGES
FEMALES	N =	16	16	15	47
	$\bar{X}$ =	45.1	43.6	53.0	47.1
	S.D. =	10.0	12.7	11.2	11.8
MALES	N =	17	14	16	47
	$\bar{X}$ =	48.9	52.8	58.3	53.3
	S.D. =	6.3	9.1	14.9	11.2
ALL SUBJECTS	N =	all times are in milliseconds			94
	$\bar{X}$ =				50.2
	S.D. =				11.9

Figure 3.12 Mean reflex time versus mean age of subject group.

Table 3.23

COMPARISON OF STERNOMASTOID STRETCH REFLEX TIMES FOR LATERAL VS. SAGITTAL PLANE STUDY

		AGE GROUP IN YEARS							
		18 - 24		35 - 44		62 - 74		AGES COMBINED	
		LAT.	SAG.	LAT.	SAG.	LAT.	SAG.	LAT.	SAG.
FEMALES	N =	16	30	16	31	15	31	47	92
	$\bar{X}$ =	45.1	62.3	43.6	62.0	53.0	74.7	47.1	66.4
	S.D. =	10.0	9.6	12.7	13.4	11.2	17.0	11.8	14.8
MALES	N =	17	30	14	29	16	27	47	86
	$\bar{X}$ =	48.9	68.2	52.8	77.1	58.3	88.1	53.3	77.4
	S.D. =	6.3	11.9	9.1	13.6	14.9	16.7	11.2	16.1
ALL SUBJECTS COMBINED	N =	all times are in milliseconds						94	178
	$\bar{X}$ =							50.2	71.7
	S.D. =							11.9	16.4

lateral study with respective groupings in the previous sagittal plane study. In both studies the electrodes were placed over the right sternomastoid muscle group and a large percentage (70%) of the subjects in the lateral study were also subjects for the sagittal study. It is seen, however, that in every subject category the average reflex time from the sagittal plane study is significantly greater than that from the lateral study. The overall average reflex time for the sagittal study was 71.7 msec., compared to 50.2 msec. for the lateral study, and in fact the average reflex time for young females in the sagittal study was greater than that for elderly males in the lateral study (62.3 msec. to 58.3 msec.). It thus appears that the reflex time for the sternomastoid muscle group is greater for movements involving extension than for movements involving lateral bending. Possible reasons for this difference are discussed in Chapter 5. In other respects, however, the results from the two studies are similar. That is, reflex times for males are greater than for females, and reflex times for males show a steady increase with age, while for females the reflex time shows a significant increase only from the middle to the elderly age groups.

E. Strength

1. General. Table 3.24 and Figure 3.13 show the average results by subject group of the strength testing in lateral flexion. Testing was performed on both sides and it is seen that the average results from right and left testing are in excellent agreement. There is only a small change in strength from the young to middle age group (males showing an increase and females a decrease) but there is a considerable

Table 3.24

ISOMETRIC PULL FORCE USING LATERAL NECK FLEXOR MUSCLES

		AGE GROUP IN YEARS											
		18 - 24			35 - 44			62 - 74			AGES COMBINED		
		RT.	LT.	AVG.	RT.	LT.	AVG.	RT.	LT.	AVG.	RT.	LT.	AVG.
FEMALES	N =	16	16	16	16	16	16	16	15	16	48	47	48
	$\bar{X}$ =	18.3	19.3	18.8	16.8	17.6	17.3	12.0	11.0	11.8	15.7	16.1	16.0
	S.D. =	6.3	7.2	6.5	5.7	7.4	6.4	4.9	4.2	4.6	6.2	7.2	6.5
MALES	N =	17	17	17	14	14	14	15	15	15	46	46	46
	$\bar{X}$ =	27.1	28.9	28.0	32.0	32.4	32.1	18.4	19.2	18.9	25.7	26.8	26.3
	S.D. =	5.1	6.6	5.6	10.0	10.7	10.2	7.2	7.0	6.9	9.2	9.7	9.3
ALL SUBJECTS COMBINED	N =	all force values are in pounds									94	93	94
	$\bar{X}$ =										20.6	21.4	21.0
	S.D. =										9.3	10.1	9.5

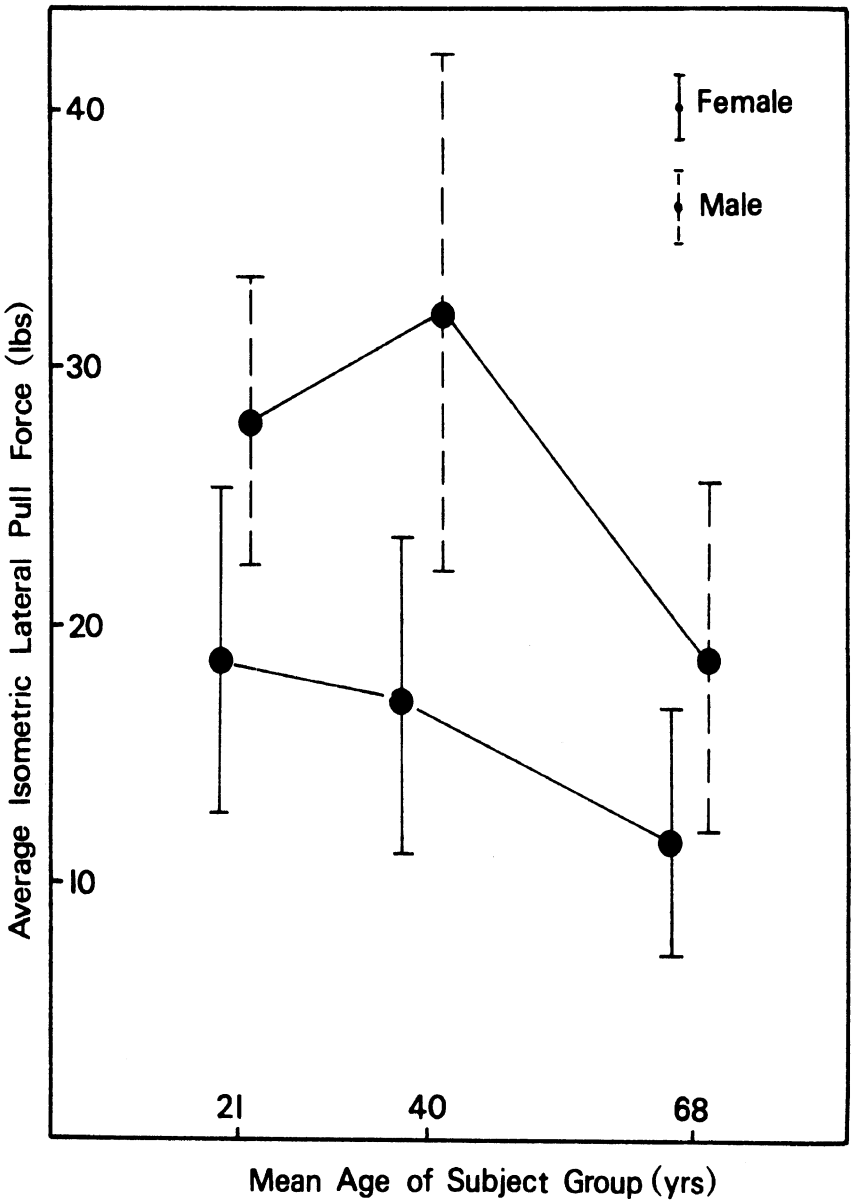


Figure 3.13 Average isometric pull force versus mean age of subject group. Brackets indicate the standard deviation of the sample.

decrease in strength for both males and females from the middle age to the elderly subject groups. There is also a considerable difference in strength between males and females, males being 1-1/2 to 2 times stronger on the average.

Table 3.25 shows a comparison of the neck strength results in lateral bending with neck strength results in flexion and extension obtained in the sagittal plane study. Lateral neck strength is seen to be considerably less than strength in extension and just slightly less than or equal to strength in flexion. It is interesting that in all cases the greatest strengths are for middle age males.

2. Calculation of Muscle Tensions. The values of neck strength presented in the preceding tables are the force values or tensions developed in a line attached about the head when the subject exerted a maximum pull with his lateral flexors. From these force values it is possible to calculate approximations of the actual muscle tension developed in the neck muscles. In a very simplified way, Figure 3.14 represents a free body diagram of the head and neck. F_y is the force developed by the subject pulling on the cord and T_s is the tension in the sternomastoid muscle groups. As shown in Figure 2.23, these are the primary muscles which attach between the head and torso. The tension, T_s, can therefore be estimate by summing moments about the occipital condyles:

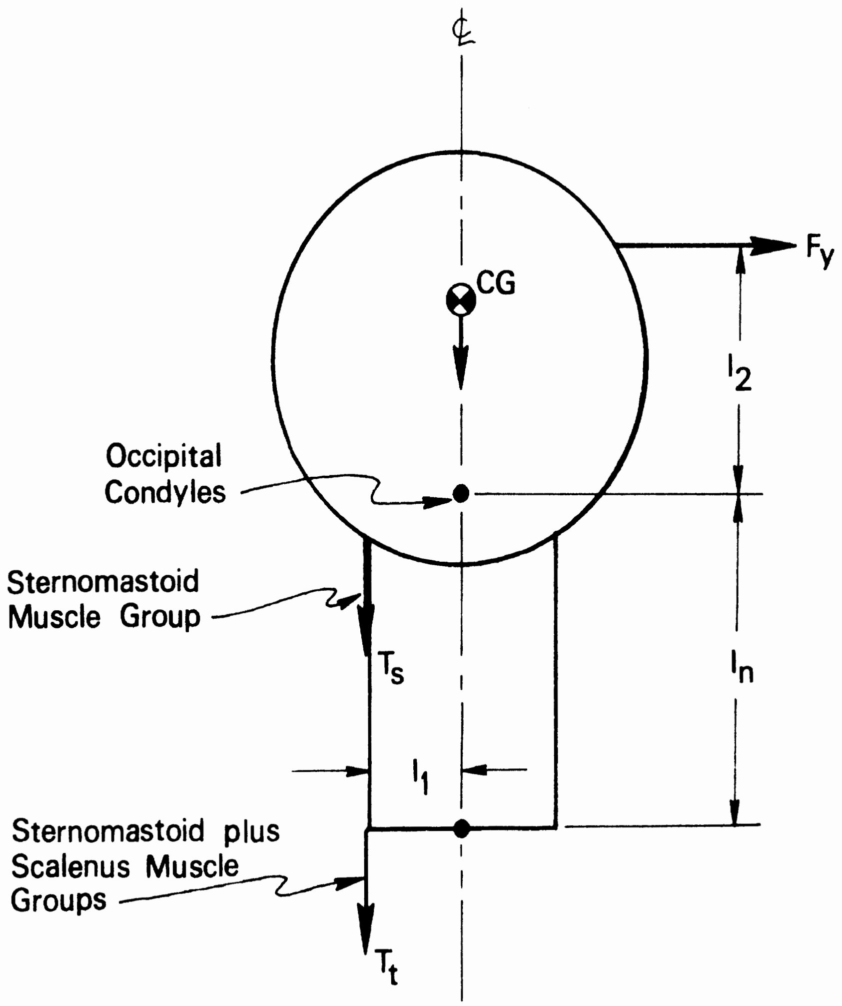
$$\Sigma M_{condyles} = 0 = T_s l_1 - F_y l_2$$

$$T_s = \frac{F_y \cdot l_2}{l_1}$$

Table 3.25

COMPARISON OF NECK PULL STRENGTHS FOR FLEXION, EXTENSION AND LATERAL PULLS

		AGE GROUP IN YEARS											
		18 - 24			35 - 44			62 - 74			AGES COMBINED		
		FLX	EXT	LAT	FLX	EXT	LAT	FLX	EXT	LAT	FLX	EXT	LAT
FEMALES	N =	31	31	16	31	31	16	31	31	16	93	93	48
	$\bar{X}$ =	19.6	27.2	18.3	16.8	26.5	17.3	13.8	22.8	11.8	16.7	25.5	16.0
	S.D. =	5.1	7.5	6.5	4.5	6.5	6.4	5.1	8.3	4.6	5.4	7.6	6.5
MALES	N =	30	30	17	30	30	14	27	27	15	87	87	46
	$\bar{X}$ =	32.4	37.7	28.0	34.8	45.1	32.1	26.3	33.9	18.9	31.3	39.1	26.3
	S.D. =	10.0	9.3	5.6	8.6	9.5	10.2	7.3	8.0	6.9	9.3	10.0	9.3
ALL SUBJECTS COMBINED	N =	all force values are in pounds									180	180	94
	$\bar{X}$ =										23.8	32.1	21.0
	S.D. =										10.5	11.1	9.5



$$T_s = \frac{(F_y \cdot l_2)}{l_1} \quad ; \quad T_t = \frac{F_y(l_2 + l_n)}{l_1}$$

Figure 3.14 Simplified free-body diagram of head and neck showing approximate relations between measured force, F_y, and muscle tensions in sternomastoid (T_s) and scalenus plus sternomastoid (T_t) muscle groups.

From anatomical observations (Grant, 1962) it can be shown that one centimeter is a good measure for the distance between the outside of the neck and the line of action of the sternomastoid muscle group. Accordingly, l_1 is equal to one-half the measured neck breadth minus one centimeter. The distance l_2 is determined by measuring the distance from the occipital condyles to tragion from x-rays and adding this to the distance from tragion to F_y, which was measured during testing.

As seen in Figure 2.23, the scalenus muscles are also involved in keeping the head and neck erect but attach from the torso along the entire length of the neck. Therefore, to include their input into the model, moments can be summed about a point at the base of the neck, say $C_7 - T_1$. In so doing, the tension developed in all the neck muscles, sternomastoid plus scalenus, is estimated by:

$$T_t = \frac{F_y \, (l_2 + l_n)}{l_1}$$

In this way muscle tension was computed from the measured pull force for use in the computer modeling of crash impact using the MVMA Two-Dimensional Crash Victim Simulation, Version 3 (Bowman et al., 1974, Robbins et al., 1974) and reported in Chapter 4. It must be considered, however, that while subjects were asked to pull with a maximum effort, the resulting tensions are probably somewhat less than would be developed in a "panic" or emergency situation. Therefore, muscle tensions up to 130% of the experimental results were used in this computer modeling.

F. Head Acceleration and Computer Simulation of Head Jerk Tests.

As mentioned in Chapter 2, one of the primary uses of the acceleration data, other than for reflex time calculations, was to provide a criterion for comparing experimental responses with each other and for validating computer models which may be used to simulate the experiment.

Figure 3.15 shows a typical set of acceleration signals obtained during a reflex test. The acceleration profiles for all subjects were similar to these; all showed, to some degree, the unexpected spike at about 10 msec. Initially it was felt that this spike must be an artifact, and every effort was made to remove it. It is, however, at a much lower frequency than the ringing or natural frequency of the accelerometer bite bar structure, and it is now considered to be a real part of the acceleration response. Its origin is, however, unexplained, although it was observed on several occasions to be decreased when the head band was positioned to cause a rotational component during the head jerk. In this regard it should be mentioned that the head band was always adjusted to obtain nearly pure lateral bend during the head jerk test. Confirmation of planar movement was made in two cases by taking high speed movies of the reflex test from both the front and lateral directions.

Using the force profile signals, various subject measurements as illustrated in Figure 2.24, head and neck mass data from Walker (1973), and measures for neck length and distances from tragion to the occipital condyles from x-ray data, computer simulations of four individual subjects were obtained using the MVMA Two-Dimensional Crash Victim Simulation Model. Subjects used for simulation were chosen according to stature to represent 5th percentile females (FBS01 and FBS04) and 95th percentile males (MAT04 and MBT01) of the subject pool.

The angular accelerations of the head obtained from the computer

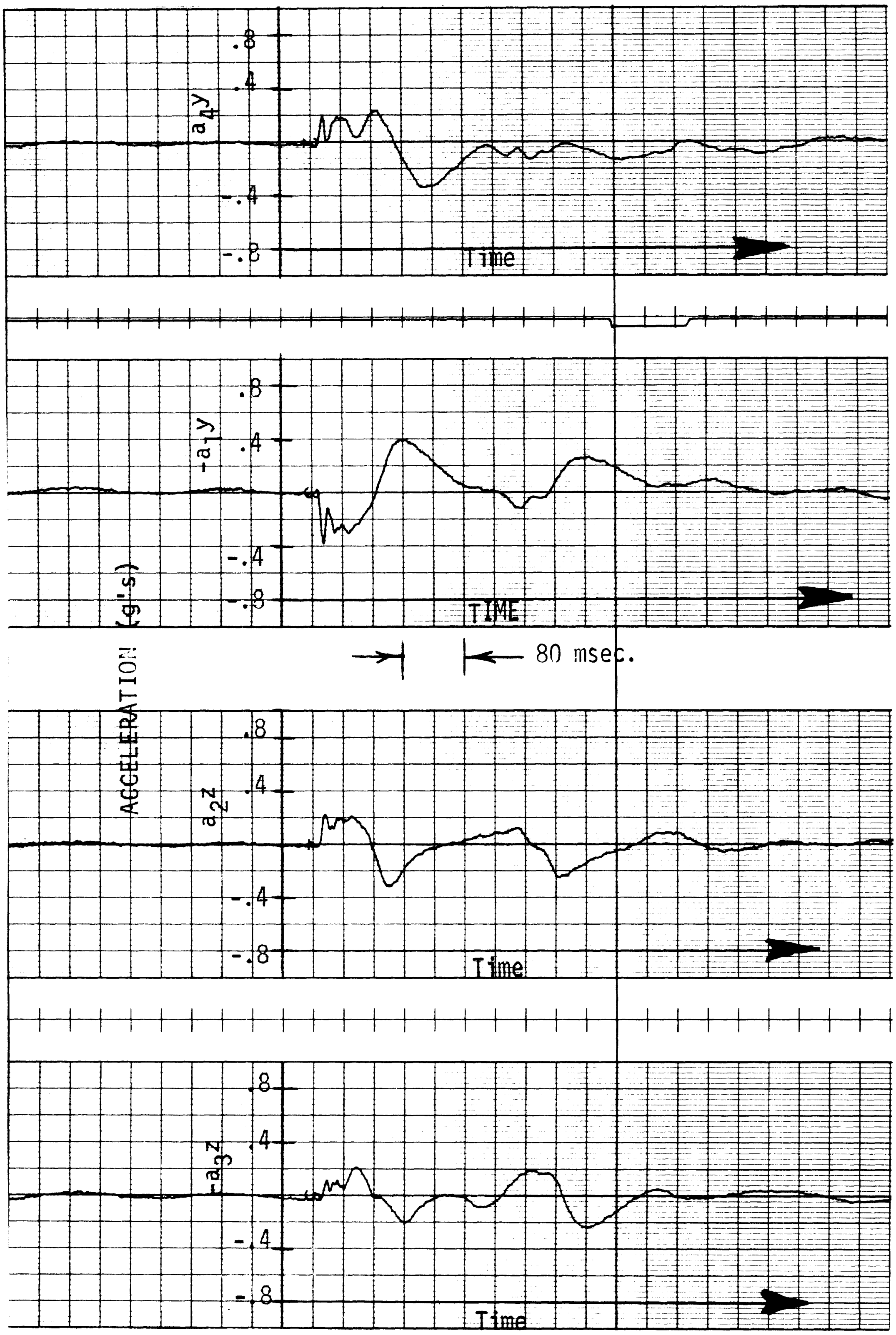


Figure 3.15 Typical acceleration signals from the four acceleromters mounted on mouth bite piece.

simulations were compared with head angular accelerations calculated by equation (6) in Chapter 2, using the experimental acceleration signals. Figures 3.16 through 3.19 show the comparisons of these results for the four subjects. A parameter, K, which represents the lateral static bending stiffness of the neck for small deformations, was adjusted to obtain, by observation, a "best fit" match between the experimental and simulated results. Prior to this exercise, an appropriate value for this parameter had been unknown, but estimated at 70 in-lb/degree. As the Figures illustrate, more appropriate values are 8 in-lb/degree to 16 in-lb/degree, depending on population segment. The "best fit" to each of the experimental curves was defined as the simulation curve for which the fundamental frequencies for angular head motion are in best agreement. For the male subjects, the amplitudes of the signals are also in good agreement, especially for subject MBT01. For the females the experimental response is considerably larger than the simulated response. This discrepancy may be due to the fact that the head and neck mass (head = 4376 gms., neck = 1625 gms.) used in all simulations was an estimate based on data obtained from 20 male cadavers (Walker, 1973). Use of a smaller head mass for females would result in a larger angular acceleration amplitude which would agree more closely with the experimental findings.

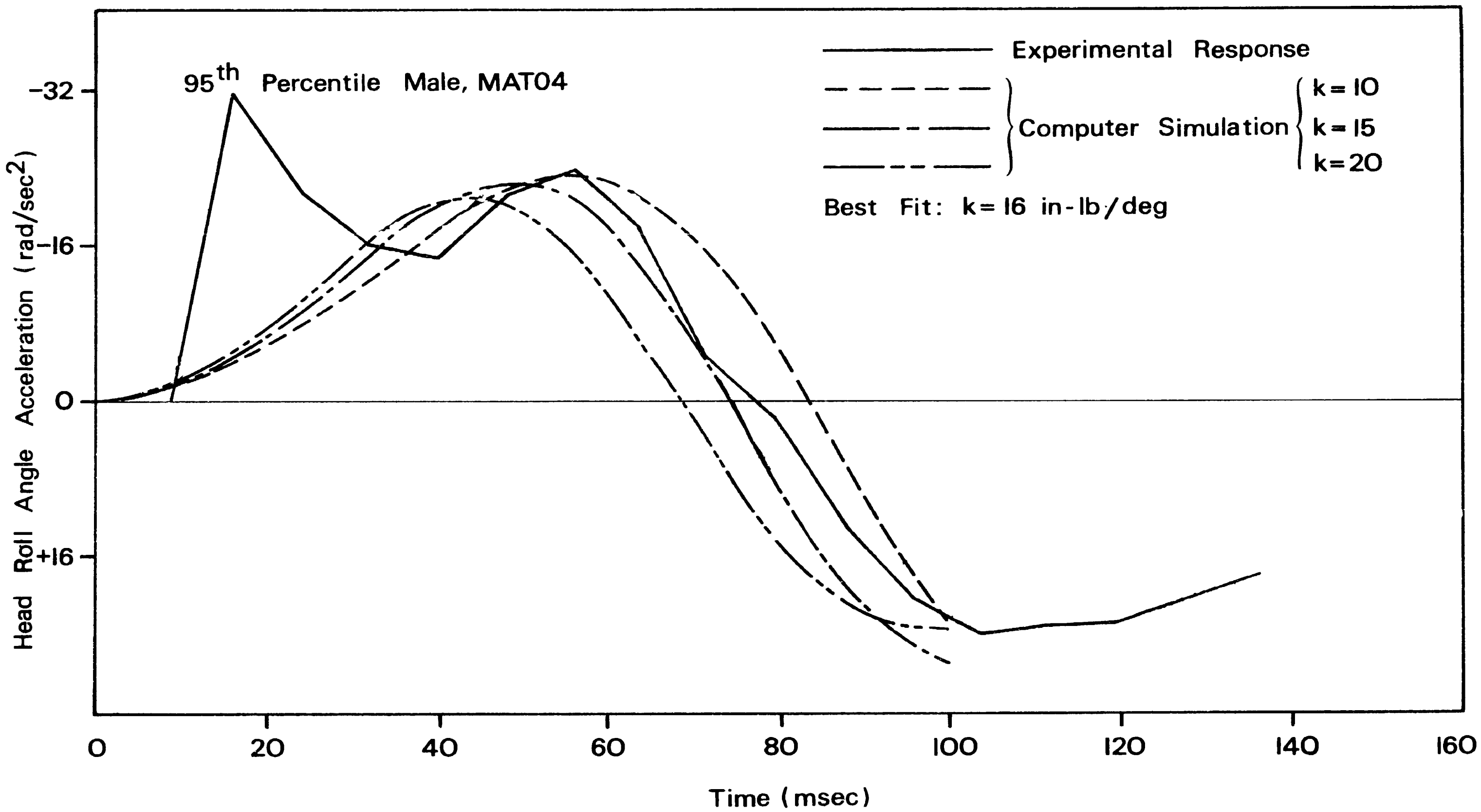


Figure 3.16 Comparison of experimental and computer simulation head angular acceleration curves for reflex test.

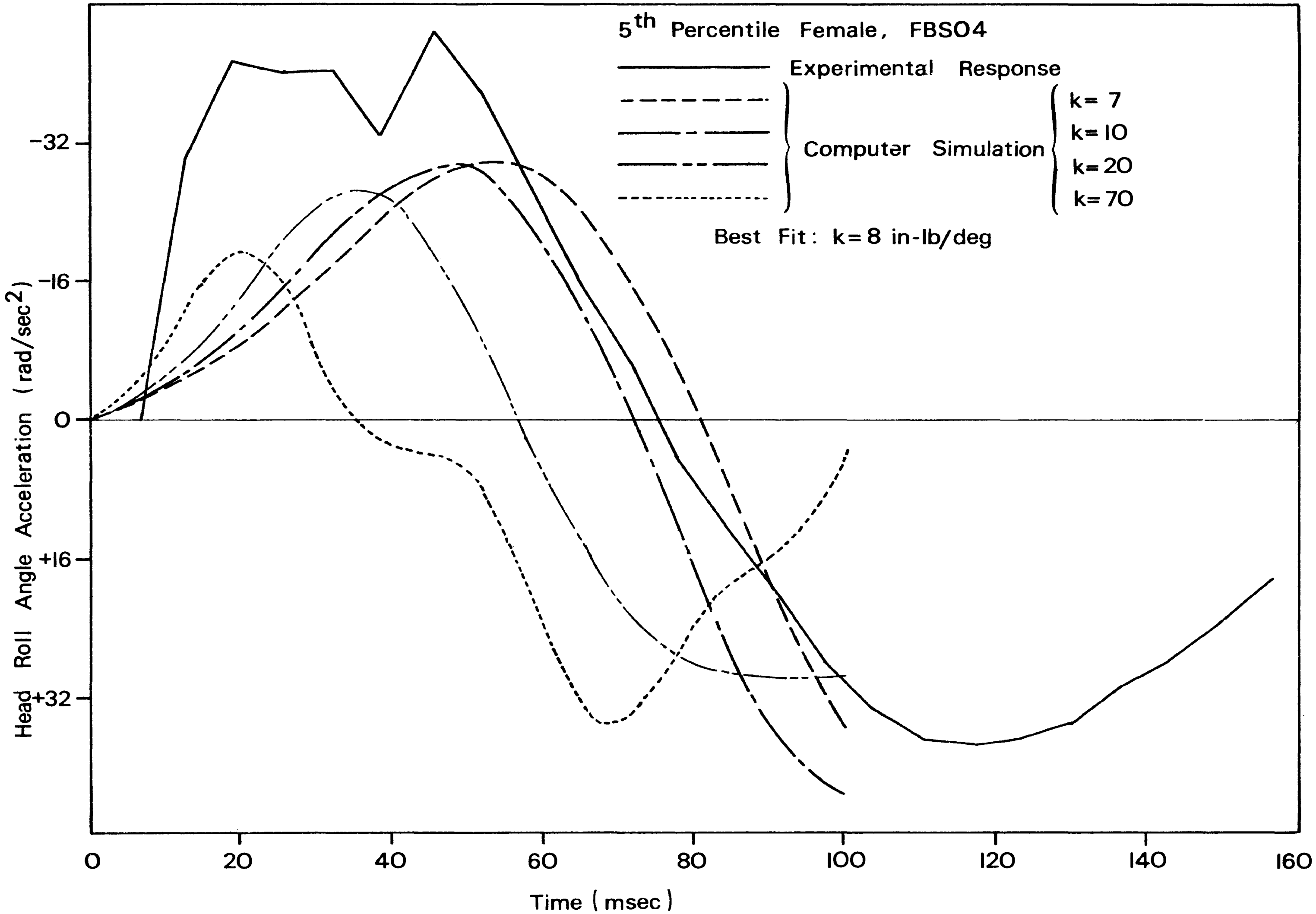


Figure 3.17 Comparison of experimental and computer simulation head angular acceleration curves for reflex test.

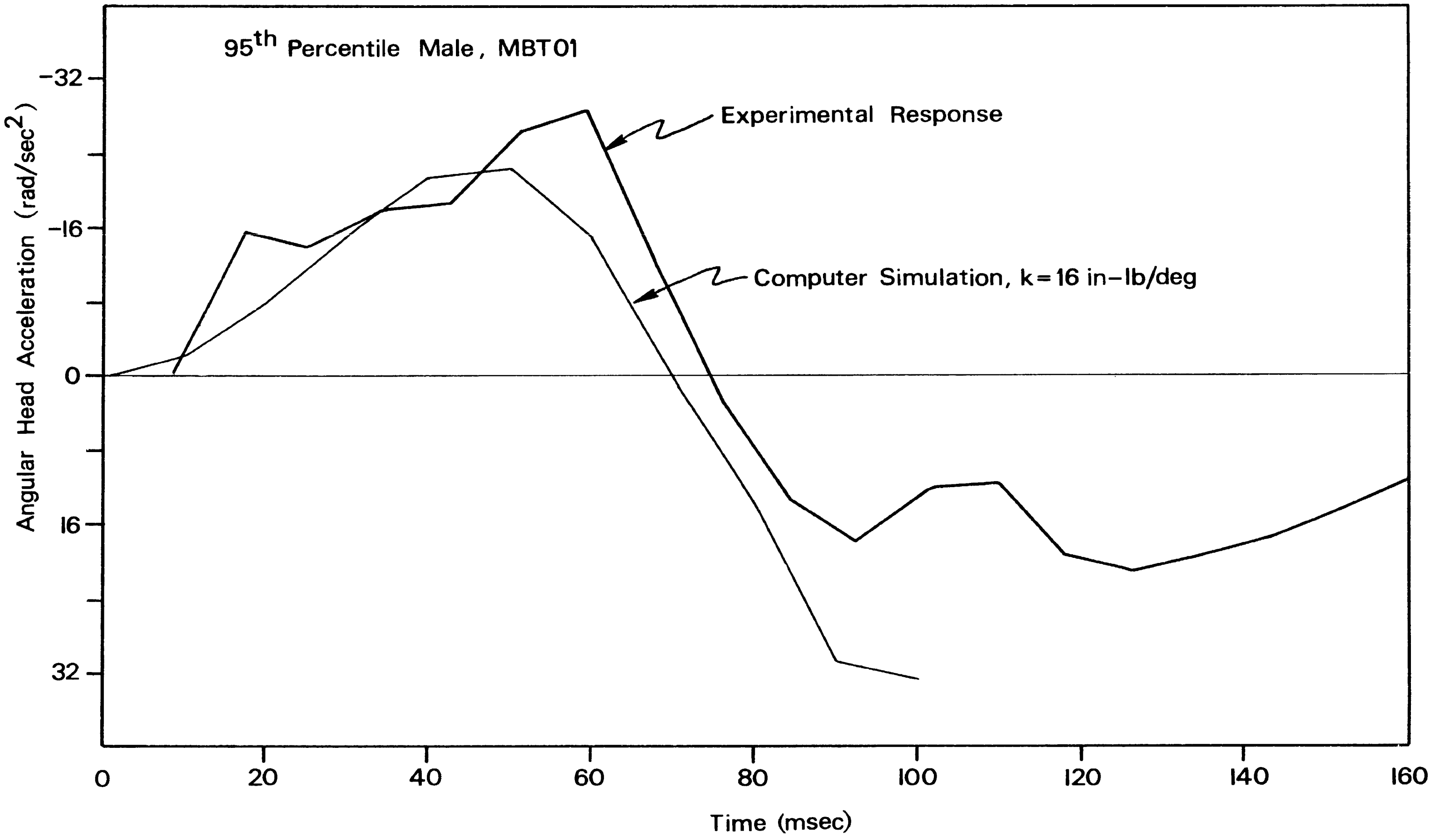


Figure 3.18 Comparison of experimental and computer simulation head angular acceleration curves for reflex test.

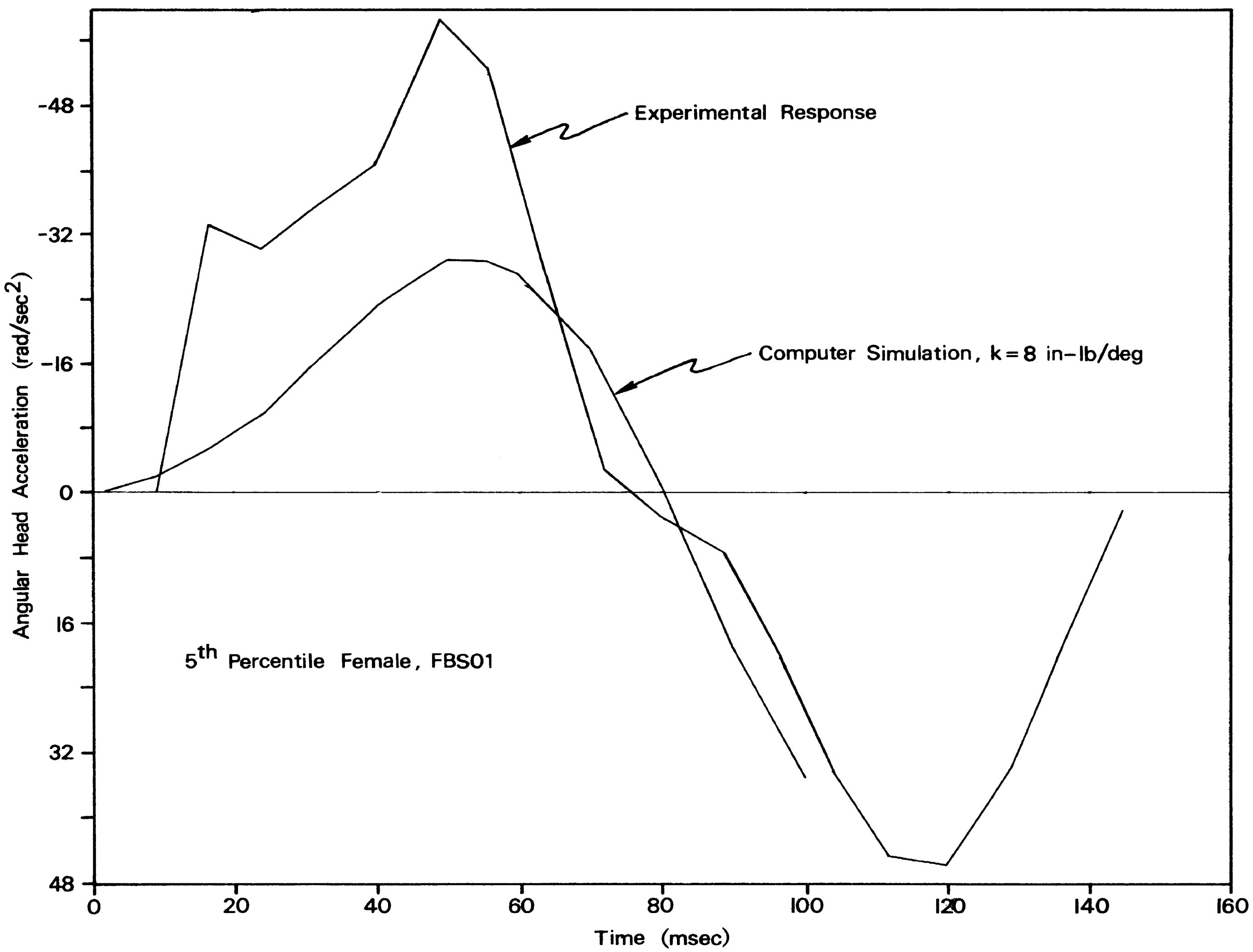


Figure 3.19 Comparison of experimental and computer simulation head angular acceleration curves for reflex test.

CHAPTER 4

BIOMECHANICAL MODELING USING TEST RESULTS

A. Objective

Much of the data from the IIHS Neck Lateral Response Study testing program is of considerable value to biomechanical modeling investigations. The test results make it possible to define pertinent biomechanical characteristics of different population segments so that mathematical models for crash simulations can be used with confidence of obtaining meaningful dynamic response data.

A series of mathematical model crash simulations was conducted as part of this study. The model used was the MVMA Two-Dimensional Crash Victim Simulation, Version 3 (Bowman et al., 1974, Robbins et al., 1974). This two-dimensional model is normally used for investigation of front-end and rear-end impact situations, but with redefinition of various input data, it is suitable for simulation of lateral impact situations as well. The obvious assumption is that motion must be contained in a lateral plane. Accordingly, it was possible to make use of much of the neck lateral-response data to simulate automobile occupants involved in side-impact intersection collisions. Pertinent data used from the testing program were lateral bend range of motion, sternomastoid muscle-group strength, reflex time, and anthropometry.

The computer simulation results presented here are analyzed with an emphasis on their qualitative characteristics. That is, parameter variations are discussed with respect to their relative significance to injury potential, but no human-tolerance data for predicting a quantitative probability or degree of injury for any particular crash simulation are included.

B. Description of Crash Simulations

1. Population Segments. The subject pool of the IIHS study was selected to define six population segments of average stature. This is discussed in Chapter 2. The six groups are females and males, age 18-24, 35-44, and 62-74. The groups are identified by the code designations shown in Table 4.1.

Table 4.1

Population Segment Code Designations

	Age 18-24	Age 35-44	Age 62-74
Female	FA	FB	FC
Male	MA	MB	MC

2. Test Run Matrix. The crash simulation test matrix is shown in Table 4.2. It is partitioned on the six population segments and has two classes of sub-elements: (a) impact velocity of the striking vehicle, and (b) degree of neck muscle contraction. Since a primary parameter of this series of crash simulations is muscular strength, the test matrix is most detailed for investigation of the strongest and weakest of the six population segments, males age 35-44 (MB) and females age 62-74 (FC). Seven crash simulations involving the strongest group were conducted, and six were conducted for the weakest group, while only three crash simulations were conducted for each of the other population segments. Each of the twenty-five test runs in the matrix is identified by a number affixed to the population segment code designation.

TABLE 4.2. CRASH SIMULATION TEST RUN MATRIX

Population Segment	Run Code	Velocity of Striking Vehicle at Impact		Neck Muscle Contraction		
		10 mph	30 mph	Muscle Reflex and Force Buildup	Pre-tensed to 100% of Maximum Voluntary Isometric Tension	Pre-tensed to 130% of Maximum Voluntary Isometric Tension
Females 18-24	FA1	X		X		
	FA2	X			X	
	FA3	X				X
Females 35-44	FB1	X		X		
	FB2	X			X	
	FB3	X				X
Females 62-74	FC1	X		X		
	FC2		X	X		
	FC3	X			X	
	FC4		X		X	
	FC5	X				X
	FC6		X			X
Males 18-24	MA1	X		X		
	MA2	X			X	
	MA3	X				X
Males 35-44	MB1	X		-	-	-
	MB2	X		X		
	MB3		X	X		
	MB4	X			X	
	MB5		X		X	
	MB6	X				X
	MB7		X			X
Males 62-74	MC1	X		X		
	MC2	X			X	
	MC3	X				X

For example, MC2 designates simulation number 2 for male crash victims in the 62 to 74-year-old group.

Impacts at 10 and 30 mph are investigated. Impact velocity of 10 mph was chosen because HSRI crash investigations indicate this is the most common impact velocity for intersection collisions. More than 95% of intersection collisions are at 30 mph or less, and a 30 mph impact represents a severe environment (Scott, 1974). Muscle contractions were varied from a condition of reflex and force buildup (unanticipated impact), through pretension at 100% of maximum voluntary effort (pre-warned of the impending collision), to muscles pretensed at 130% of maximum voluntary effort (a contraction simulating "panic strength," as estimated by Chaffin and Baker [1970]).

3. Side Impact Collisions. All simulations in the test series examined the dynamic response of a right-front-seat passenger through the first 200 msec of the collision. The crash victim is seated in a stationary intermediate-size American automobile that is struck at right angles at the center of the right side of the vehicle. The occupant is unrestrained so that, except for gravity, seat cushion normal force, and seat friction, no forces act on him until he is struck by the door. Figure 4.1 is a schematic of the initial occupant configuration, showing the force-generating contact ellipses and vehicle-interior contact surfaces. The struck-vehicle occupant compartment acceleration profiles are for striking-vehicle impact velocities of 10 and 30 mph. These profiles are shown in Figure 4.2. The 30 mph profile results from side-impact collision studies done by Severy (1959). As noted previously, the preponderance of intersection-type collisions are at impact velocities nearer 10 mph than 30 mph, so it

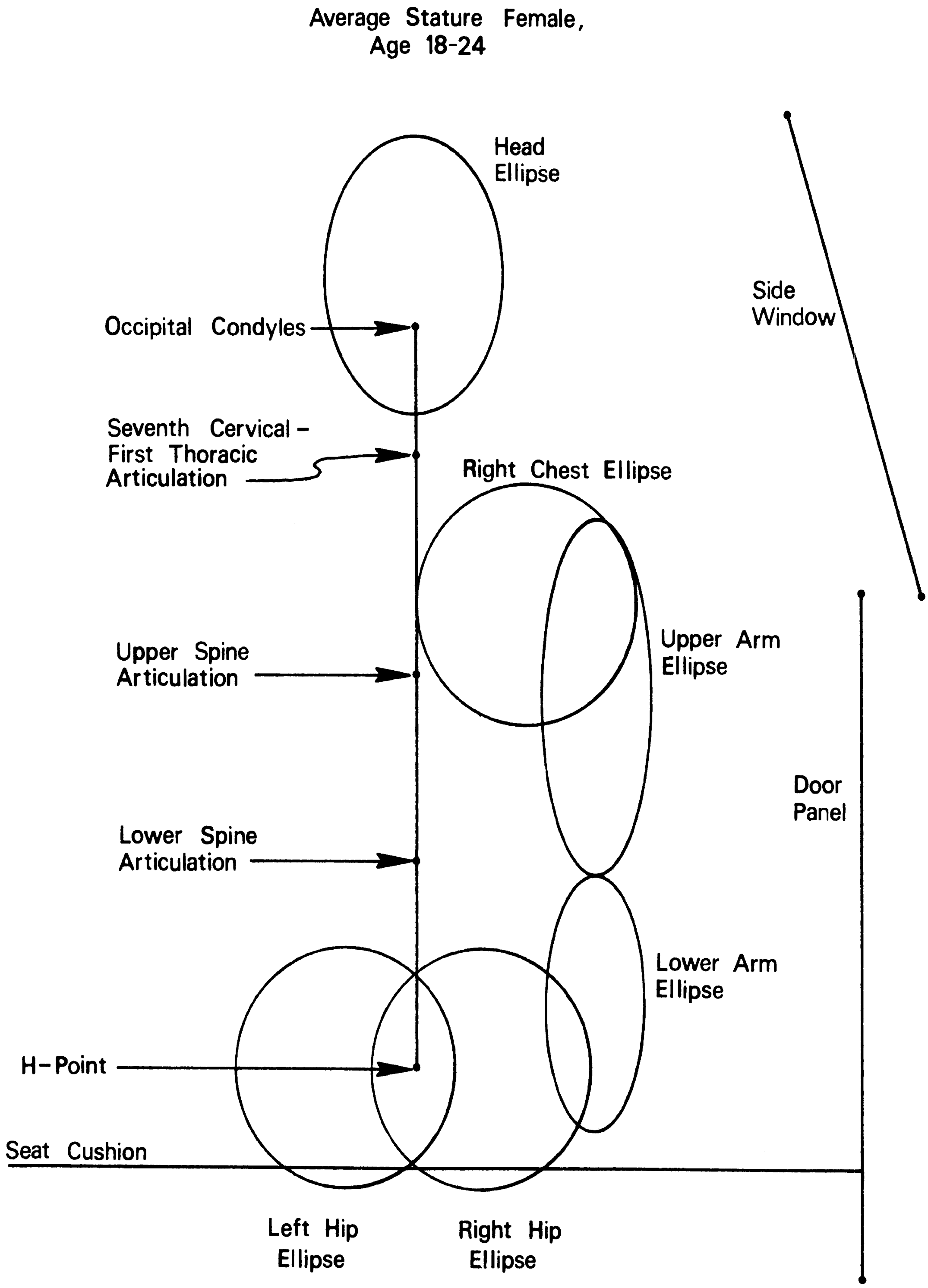


Figure 4.1 Rear profile of typical crash victim.

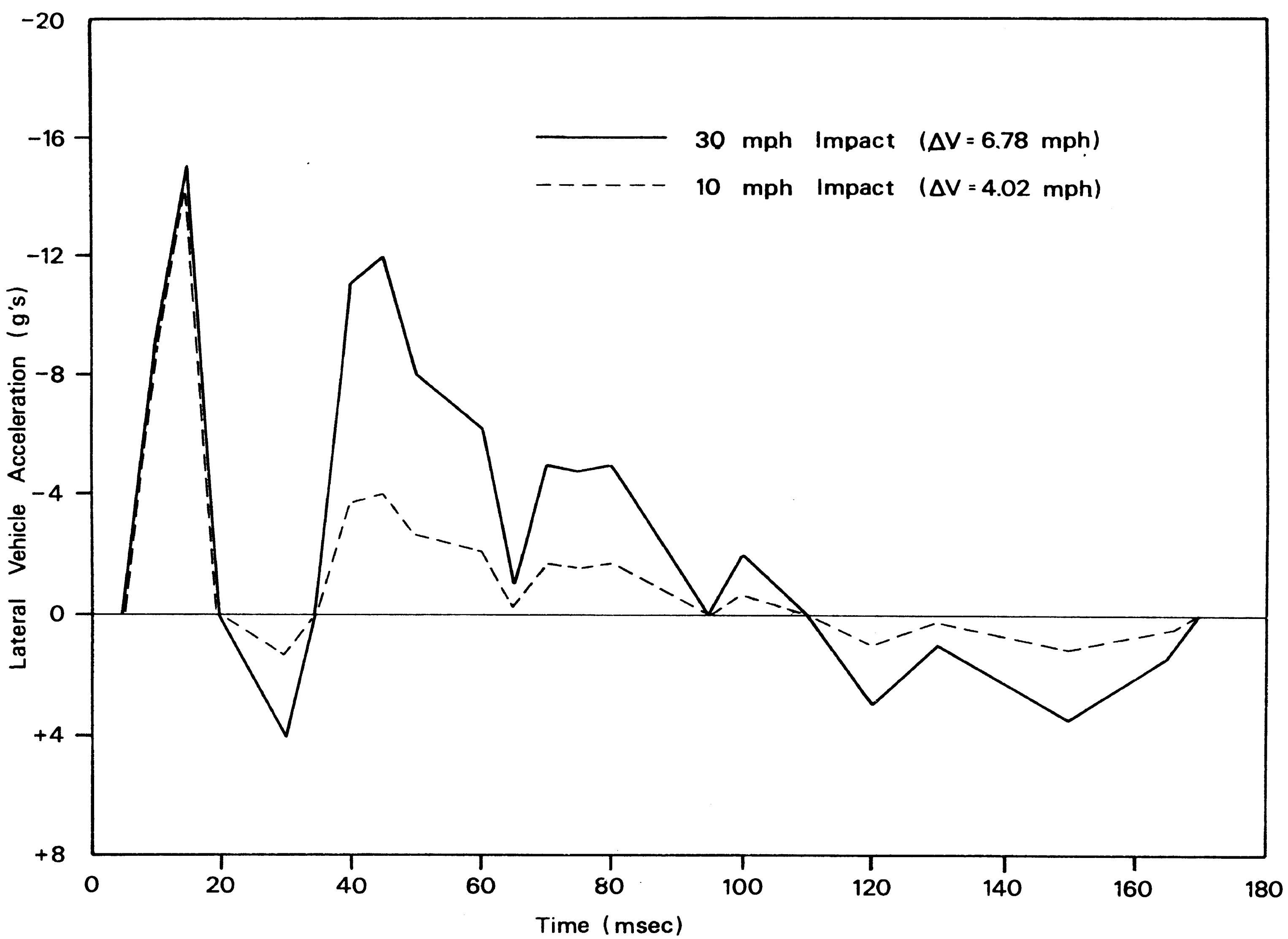


Figure 4.2 Lateral acceleration of struck vehicle.

was thought particularly useful to investigate these lower-speed impacts. Unfortunately, no occupant-compartment acceleration profiles are available in the literature for collisions of this description. It was necessary, therefore, to scale the 30-mph profile to what is thought to be a reasonable approximation of a 10-mph profile.

4. Muscle Contraction. The MVMA Two-Dimensional Crash Victim Simulator represents muscle groups in the body by Maxwell elements, springs and dampers in series, as illustrated in Figure 4.3. Both the stiffness and the damping coefficient are functions of the degree of muscle activation, M(t). M is a function of time, and its form depends in general on reflex time and muscle contraction time. It reaches a maximum value corresponding to maximum voluntary isometric muscle strength. Three states of neck muscle activation at impact are considered in this series of simulations. The functions M(t) are illustrated in Figure 4.4. The last two of these functions represent pre-tension of the muscles at 100% and 130% of voluntary maximum isometric tension. These represent situations in which the crash victim has anticipated the impact. The first function assumes that the crash victim was not aware of impending impact and that his muscles activate to 100% of voluntary maximum only after a reflex time, t_R (from 42.8 to 58.3 msec for the population), and a contraction time, t_c, taken as 120 msec.* The crash victim in the MVMA model has a two-joint neck. For side impact, the sternomastoid muscle group is represented to restrict angulation at the occipital condyles (or upper neck), while the scalenus group restricts angulation at the seventh-cervical/first-

* This typical value of contraction time was determined from tests on two male subjects, both age 32.

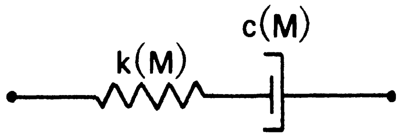


Figure 4.3. Muscle element.

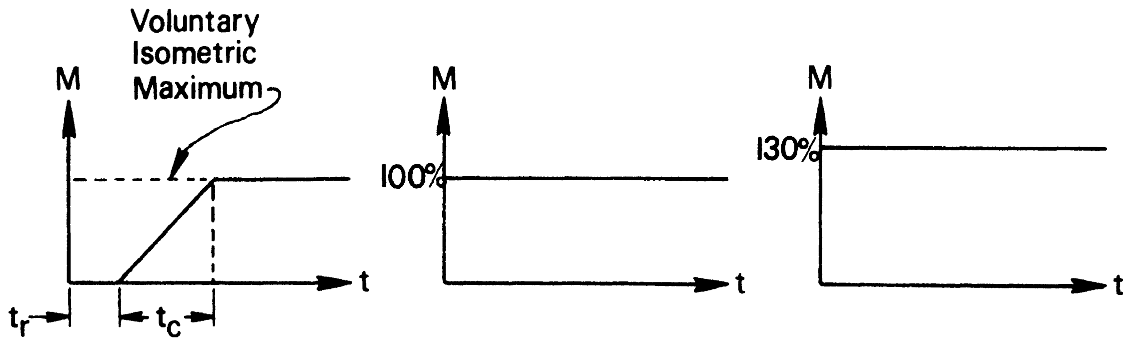


Figure 4.4 Neck muscle contraction profiles for muscle reflex and force buildup, and pretensions at 100% and 130% maximum muscle strength.

thoracic articulation (or lower neck). (See Figures 2.23 and 4.1)

C. Computer Simulation Results

Figures 4.5 and 4.28 show results from the series of computer simulations. Although the numerical integration time step was one msec, the plot increment for the figures is 5 msec. No attempt was made to join plotted points by smooth curves. (These Figures are grouped together at the end of the chapter.)

1. Head/Neck Lateral Bend Motion. Figures 4.5 and 4.10 show lateral bend motion of the head with respect to the torso resulting from 10- and 30-mph side impacts. The only crash simulation of the twenty-five in the test matrix for which the crash victim's neck muscles are relaxed for the duration of the impact is MB1, a 10-mph impact involving a male from the 35-to-44-year-old age group. It may be seen from Figure 4.9 that even for this low-velocity impact, relative head roll exceeds the average voluntary lateral bend range of motion for this population segment.

Of the six population segments defined for this study, males 35-44 are the strongest. Figure 4.9 shows a marked reduction in head angulation for the cases in which the neck muscles are contracted (MB2 to MB7), as compared with the relaxed neck simulation, MB1. In fact, even for 30-mph impacts, the muscle strength of this group is sufficient to limit head angulation to less than the range-of-motion "stop" whenever the muscles are pre-tensed, and it is nearly sufficient even for the case of muscle reflex and force buildup. The effect of muscle contraction seen here contrasts sharply with that for the weakest of the six population segments, females age 62-74 (FC). Figure 4.7

shows that for this group neck muscle strength is insufficient to prevent head angulations exceeding the voluntary motion limit even for 10 mph impact.

Figures 4.5 and 4.8 also provide an interesting comparison of the effect of muscle contraction for different population segments. These figures show results for the two groups with the largest voluntary lateral bend range of motion -- females and males age 18-24. While the range-of-motion limits are nearly the same, and although simulations for neither group show angulation exceeding the voluntary limits, the greater neck strength of the males is sufficient to provide a considerably larger safety margin.

All of the Figures 4.5 to 4.10 show that motion is most limited for pre-tensed muscle contraction to 130% of voluntary isometric strength and that it is least for force buildup during muscle contraction beginning after a reflex time typical for the population segment. Figures 4.7 and 4.9 demonstrate clearly that the difference between the cases of force buildup, 100% pre-tension, and 130% pre-tension is least for the weaker members of the population and greatest for the stronger members. Also, it is interesting to note from Figure 4.9 that anticipating impact (pre-tension) has more effect in limiting angulation (relative to angulation for reflex-time and force-buildup) for low-velocity impacts than for high-velocity impacts. That is, the difference in maximum angulation for the MB3 and MB5 curves is greater than for MB2 and MB6. The reason for this is simply that occupant interaction with the vehicle interior occurs sooner for high-velocity impacts, and thus significant relative angulation of body segments begins nearer to the beginning of muscle contraction.

Figures 4.11 and 4.12 show the relative head angle performance envelopes for the entire population of this study for both 10- and 30-mph side impacts. These envelopes include the maximum and minimum values from the combination of Figures 4.5 through 4.10.

2. Head Resultant Accelerations. Figures 4.13 to 4.24 contrast a variety of response quantities for groups FC (females, 62-74) and MB (males, 35-44) for both 10- and 30-mph impacts. It may be anticipated from the near coincidence of head-angle curves in Figure 4.7 that other quantities for FC (such as resultant head acceleration, neck shear forces, etc.) differ little for the cases of muscle force build-up, 100% pre-tension, and 130% pre-tension. Accordingly, only 100% pre-tension results are shown for FC in Figures 4.13 to 4.28. There is considerably more difference between the head angle curves for MB in Figure 4.9. Therefore, MB results are given for all cases of muscle contraction. Results in Figures 4.13 to 4.28 are shown only for 100 to 200 msec, since nothing of interest happens in these simulations while the crash victim is sliding across the seat toward contact with the door.

Figures 4.13 to 4.16 show that peak head center-of-mass resultant linear accelerations can be considerably higher for a 30-mph intersection collision than for a similar 10-mph side impact. Further, for the 30-mph impact, resultant head accelerations are somewhat larger for MB than for FC. The stronger neck muscles of the MB group cause a trade-off in relative magnitude of motion in the angular and linear modes. In terms of injury potential, however, stronger neck muscles cause a decrease in magnitude of angular motions that is much more significant than the concomitant increase in linear motion. Even for MB3, which has the largest linear head acceleration, the Severity Index (SI) is only 630, while the Head Injury Criterion (HIC) is 489 (Gadd, 1966; DOT49CFR Part 571). Both are well within specified "safe" limits. Figures 4.7 and 4.9 indicate that the stronger neck muscles in the MB group limit angular motion to safe extremes for a 30-mph impact. Angulation for the FC group exceeds the voluntary range of motion and results, it may be hypothesized, in a higher probability of neurological deficit and of damage to ligaments, intervertebral discs, and vertebrae in the neck. The neck-moment spikes resulting from head angulation exceeding voluntary range-of-motion limits in the FC group are seen in Figures 4.21 and 4.23.

3. Neck Moments and Shear and Axial Forces. Excessive shear and axial forces at the occipital condyles have been hypothesized to be agents of injury. Figures 4.17 to 4.20 show them to be considerably larger for a 30-mph impact than for a 10-mph impact. (Axial forces of nearly 700 lbs. are seen in Figure 4.20. This is much smaller than the force required to produce the "hangman's fracture" of the second cervical vertebra, about 2000 lbs. (North Amer. Aviation, 1965; Portnoy et al., 1971).) Also, peak values are seen to be somewhat larger for cases of stronger muscle strength or greater degree of muscle activation. This is an expected effect of the reduction of angular motion.

Figures 4.21 to 4.24 show neck moments at the occipital condyles and at the seventh-cervical/first-thoracic (C7-T1) articulation. The resultant moment is in each case a sum of contributions from biodynamic muscle contraction and linear (soft) and nonlinear (hard) resistance to lateral bending. The nonlinear contribution results from angulation beyond the voluntary range-of-motion limits, and it accounts for all of the spikes on these curves. The nonlinear resistance represents, initially, stretching of ligamental tissue, and, with further angulation, vertebra-against-vertebra contact.

4. Biodynamic Muscle Tension. Although the likelihood of injury resulting from angulation beyond the voluntary limits is lessened by contraction of the neck musculature, there is an increased probability of damage to muscle tissue itself. In a dynamic situation, tension in the contracted muscles may reach considerably larger values than the maximum tension that the crash victim could voluntarily exert isometrically. The reason for this is that the rate of dynamically forced lengthening of the muscle may be too large for the muscle to accomodate by relaxation of its length. Excessive tensions may thus be reached even though the muscle length is never greater than its relaxed, unstretched length. Such tensions may result in tearing of individual muscle fibers.

The sternomastoid and scalenus muscle groups are the ones of greatest importance in limiting the lateral flexion which results from a side impact. Predicted biodynamic tension in these muscle groups is shown in Figures 4.25 to 4.28. Negative force values indicate tension in the left-side muscle group; positive values are for right-side tension. (All of the intersection collisions simulated for this investigation are for passenger-side impact.) Maximum sternomastoid tension for females is 389% of maximum voluntarily developed tension; for males it is 221%. Corresponding figures for the scalenus group are 317% for females and 223% for males.* Hence it might be expected that

* Maximum voluntary tensions for the sternomastoid and scalenus muscle groups were determined experimentally for this study, as described in Chapter 3, Section E.2.

muscle damage will be more likely in weaker segments of the population, even though the biodynamic muscle tensions developed in a crash situation are smaller than for the stronger population groups and even though muscle contraction is less effective in limiting injury resulting from excessive angulation.

D. Summary of Results and Conclusions

1. Neck muscle contraction may significantly lessen the likelihood of hard-tissue injury resulting from excessive lateral flexion. For stronger members of the population (e.g., males age 35-44) it may prevent such injury even for side-impact velocities of 30 mph. For weaker members of the population (e.g., females age 62-74), however, muscle strength is insufficient to prevent probable injury even for 10-mph impact.

2. Excessive lateral flexion injury is less likely when the neck musculature is voluntarily or involuntarily pre-tensed as a result of anticipation of impending impact.

3. Excessive lateral flexion injury is more likely in older members of the population than in younger because of both a more restricted voluntary range of motion and weaker neck muscles. Greater reflex time is a secondary disadvantage of older persons. Also, to the extent that an older person is less likely to be aware of impending impact (perhaps because of either being a passenger instead of the driver or because of hearing impairment), he is at further secondary disadvantage.

4. There is evidence for an increased likelihood of muscle tissue

damage when muscles are contracted, particularly at higher impact speeds. This type of injury is predicted to be most likely in weaker members of the population.

5. Results presented here are in general agreement with results of an earlier study, also sponsored by the Insurance Institute for Highway Safety (Robbins et al., 1974). That study was of rear-end collisions and therefore investigated only mid-sagittal plane flexion and extension of the cervical spine. Both investigations, however, predict that weaker and older segments of the population have greatest susceptibility to hyperflexion-related injury.

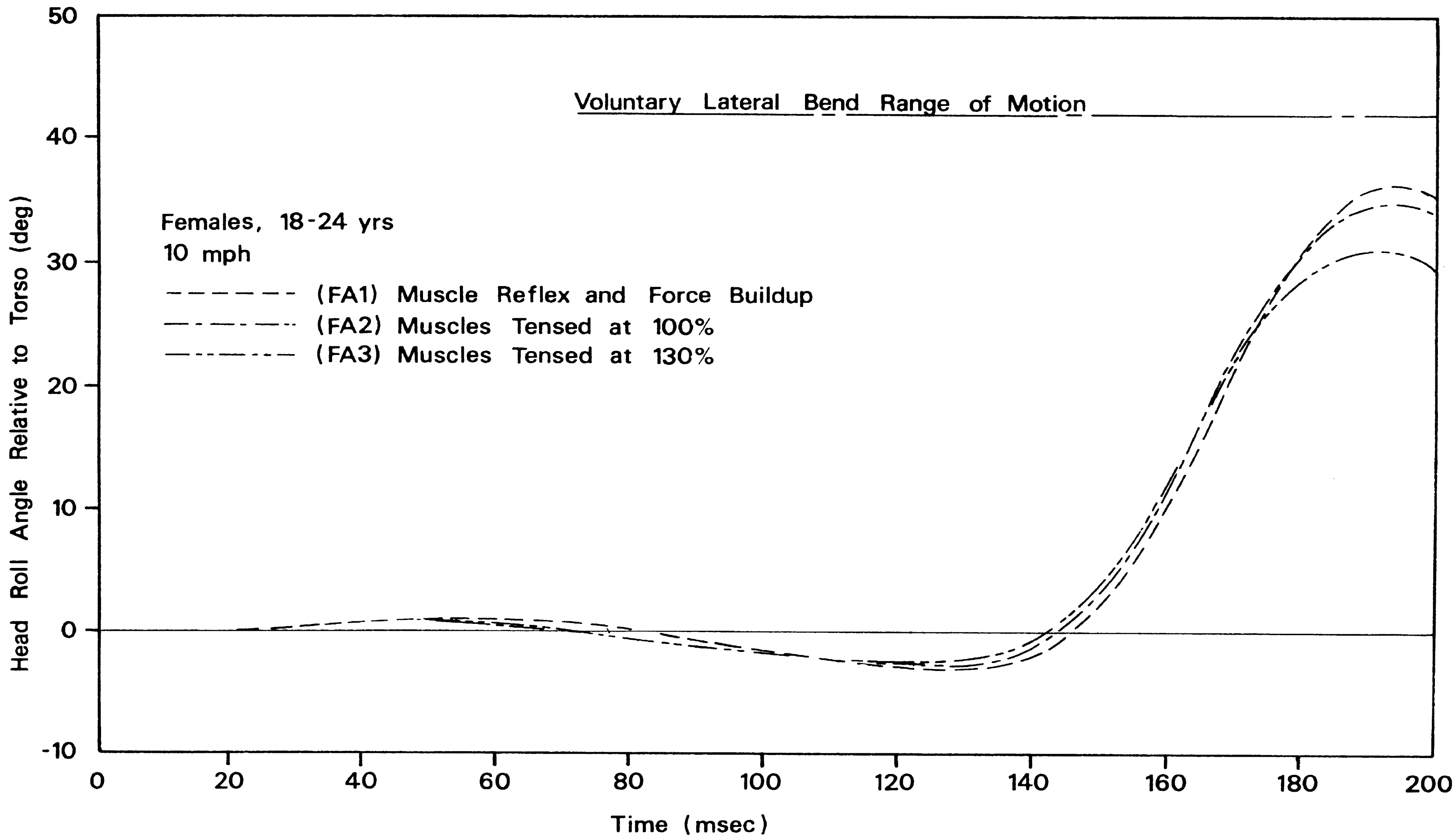


Figure 4.5 Head-torso relative angle for females, 18-24 years.

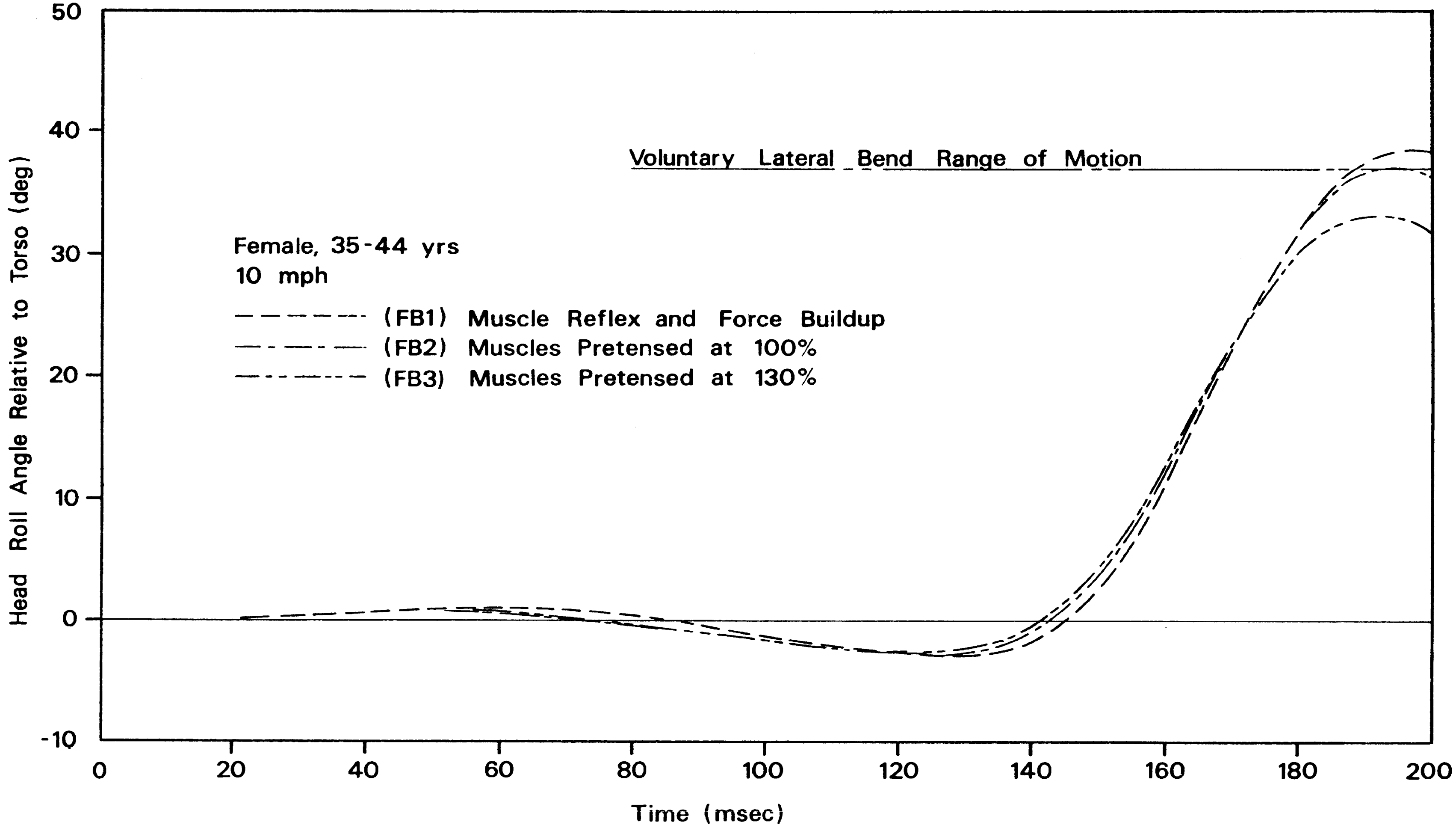


Figure 4.6 Head-torso relative angle for females, 35-44 years.

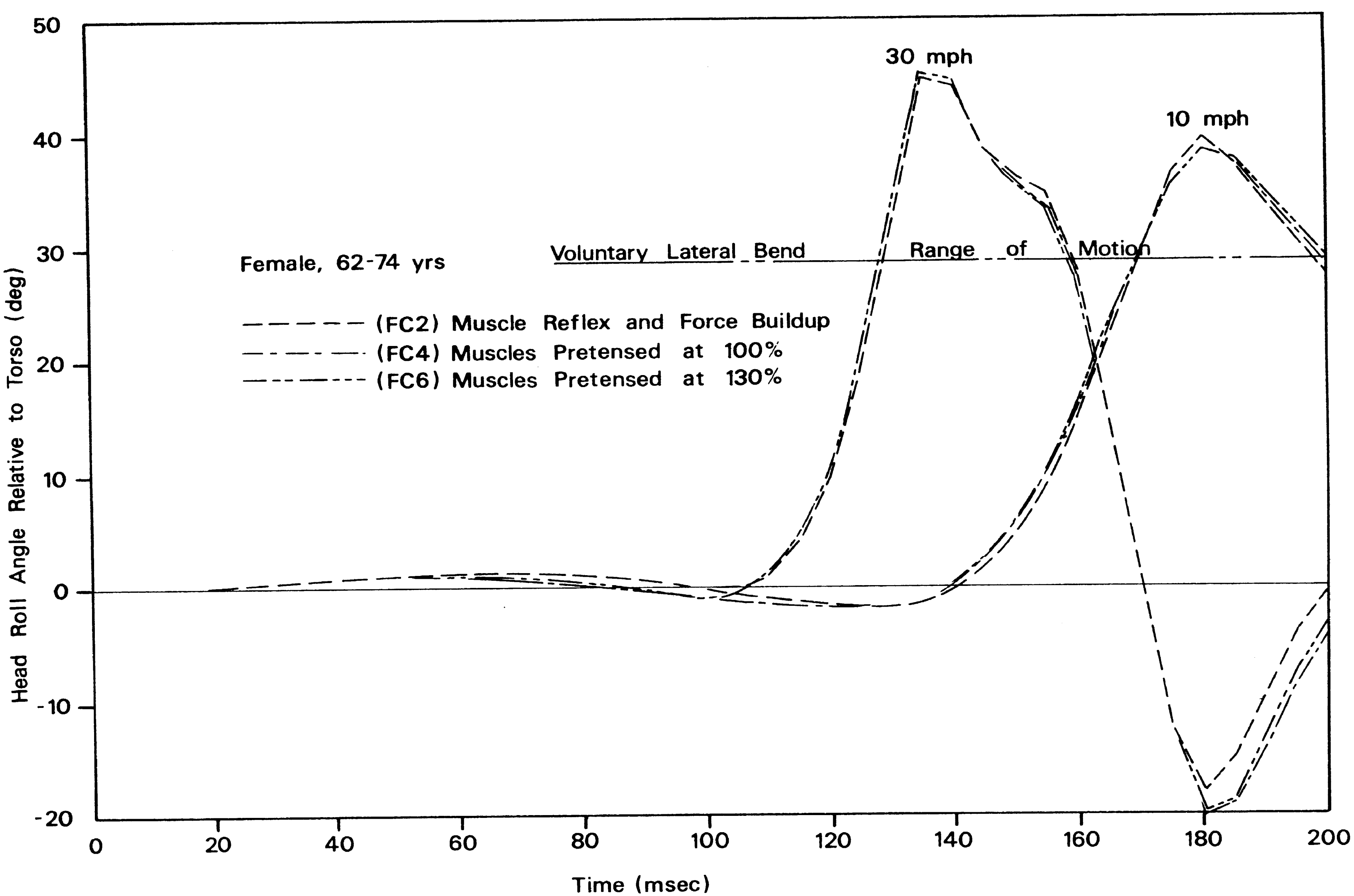


Figure 4.7 Head-torso relative angle for females, 62-74 years.

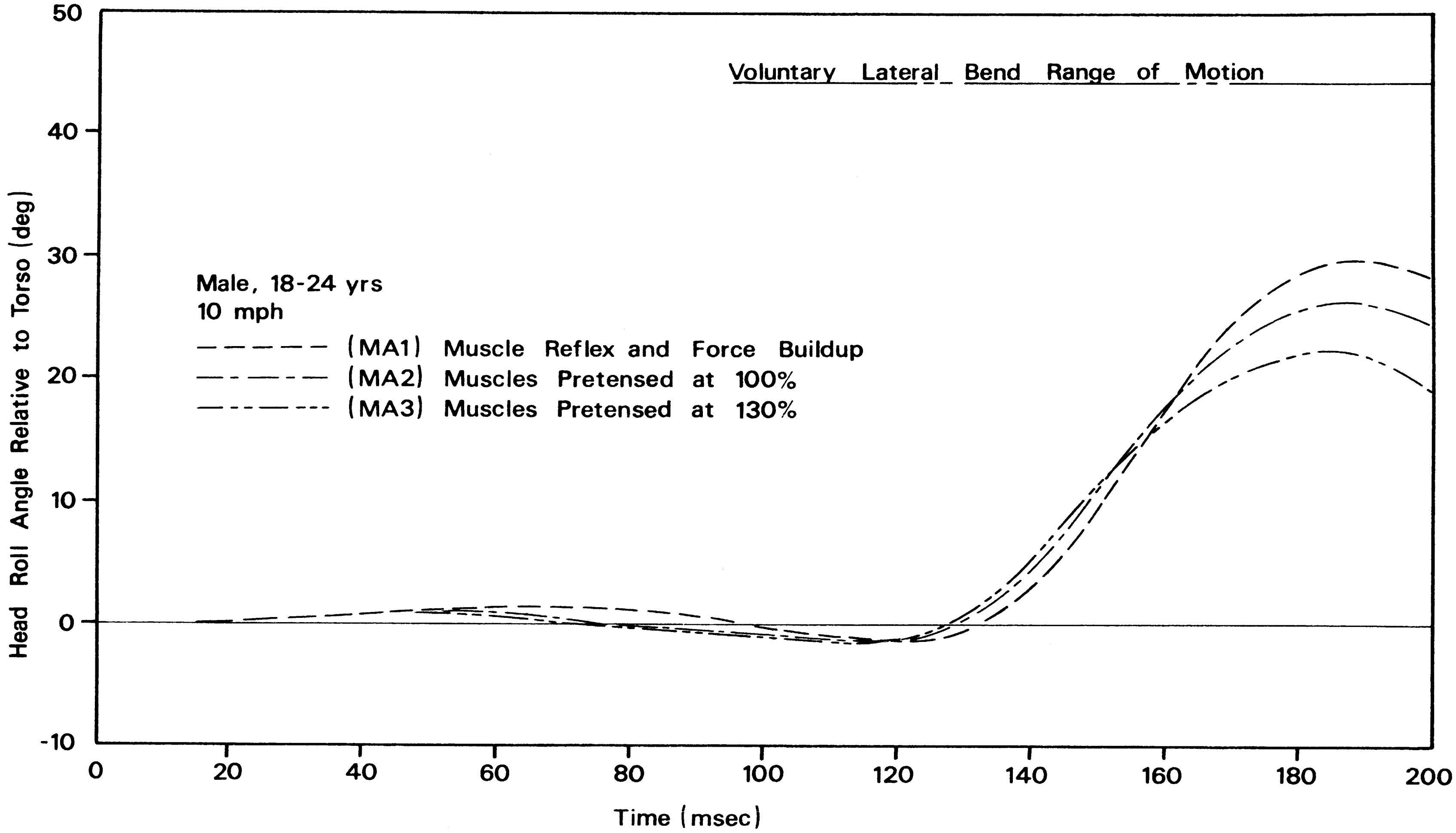


Figure 4.8 Head-torso relative angle for males, 18-24 years.

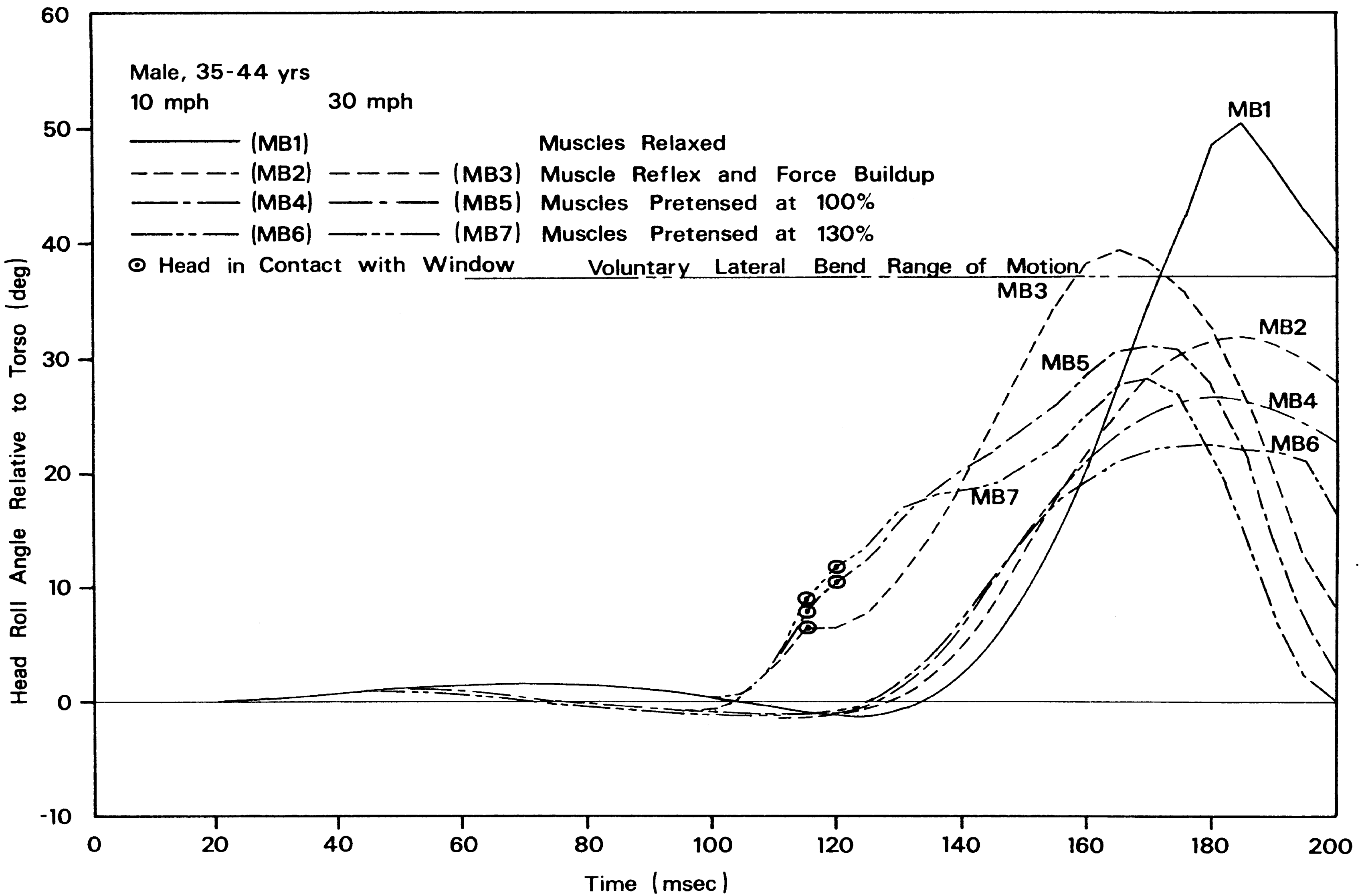


Figure 4.9 Head-torso relative angle for males, 35-44 years.

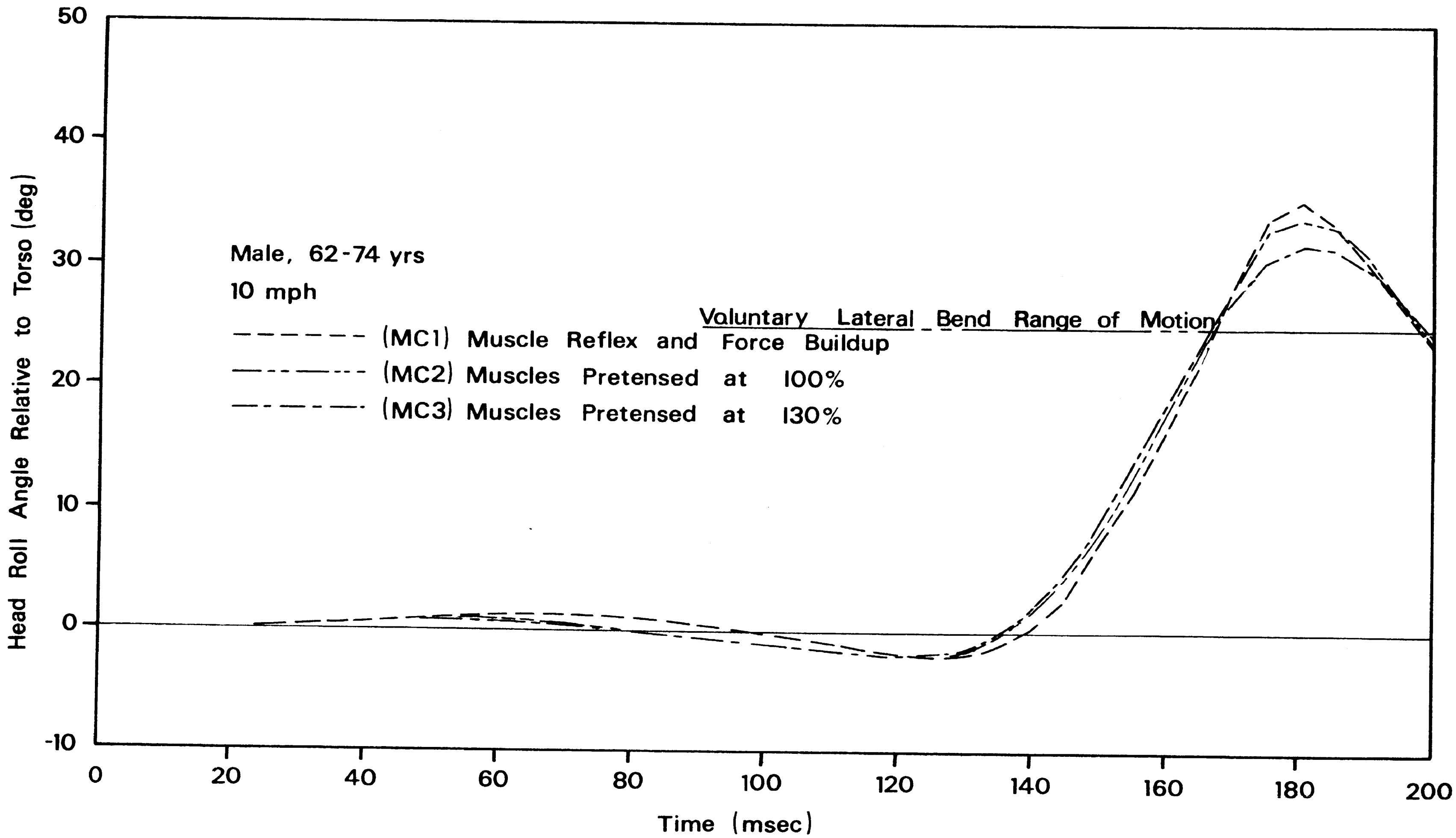


Figure 4.10 Head-torso relative angle for males, 62-74 years.

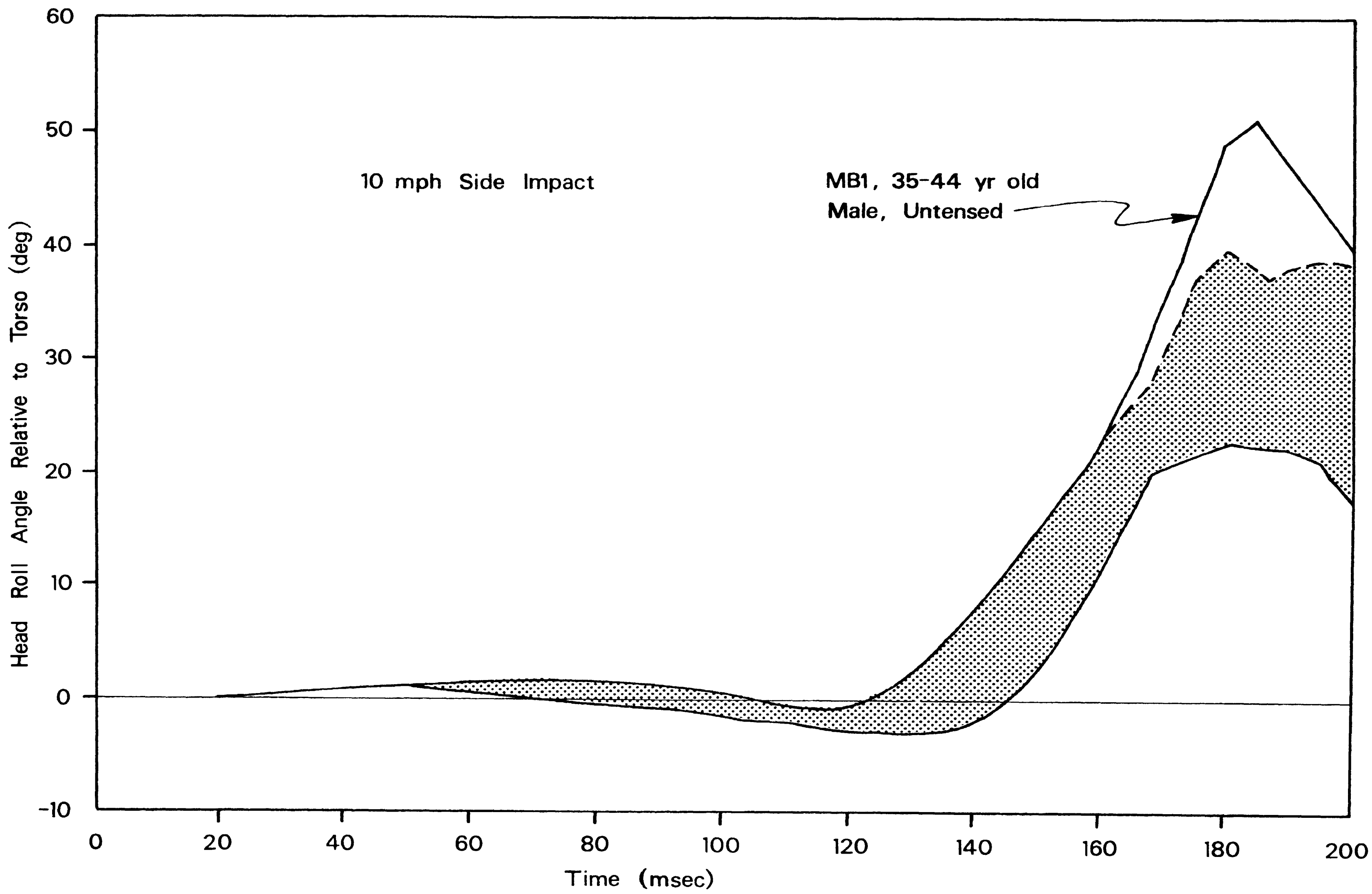


Figure 4.11 Head-torso relative angle, IIHS population (10 mph side impact).

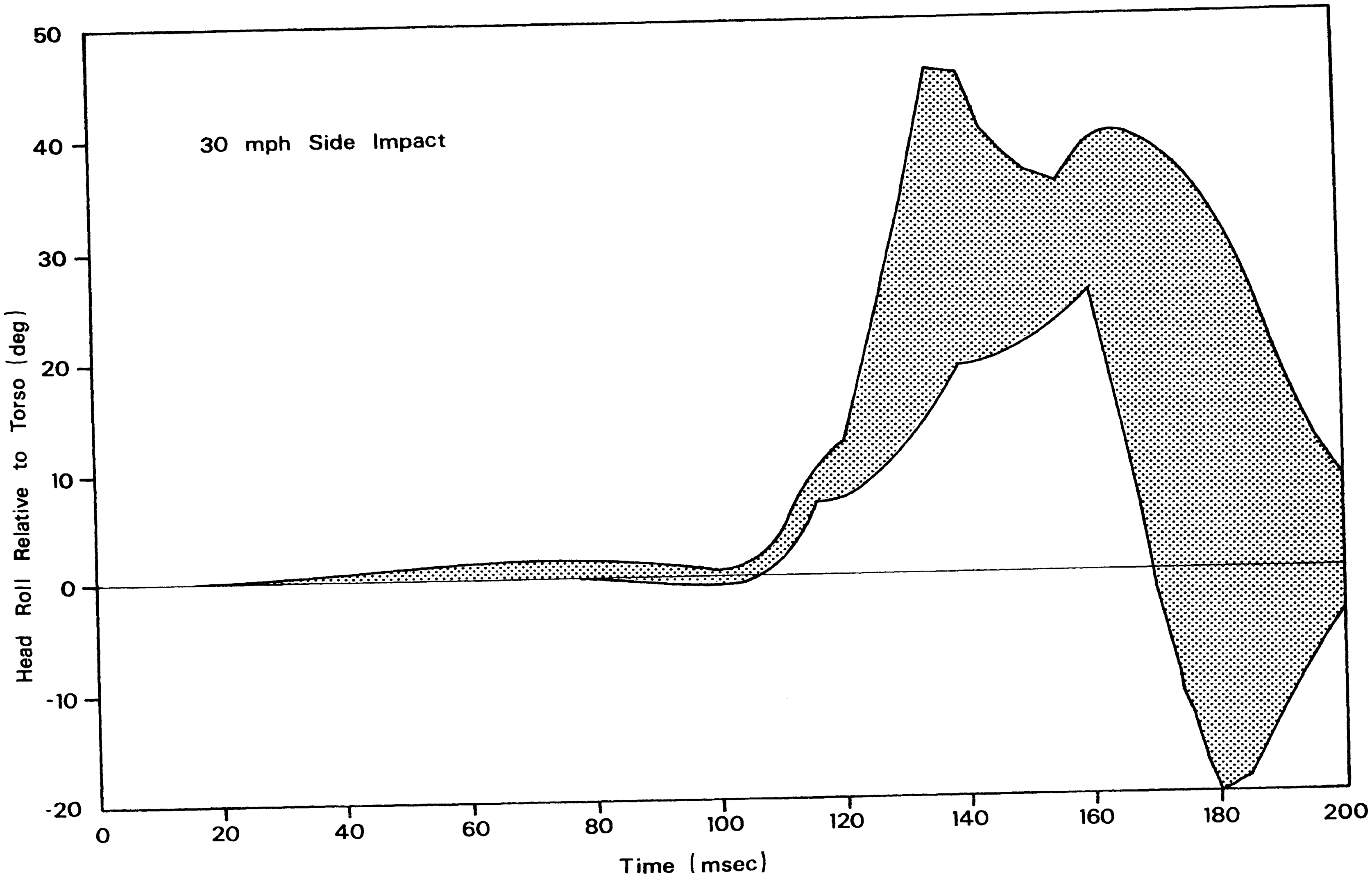


Figure 4.12 Head-torso relative angle, IIHS population (30 mph side impact).

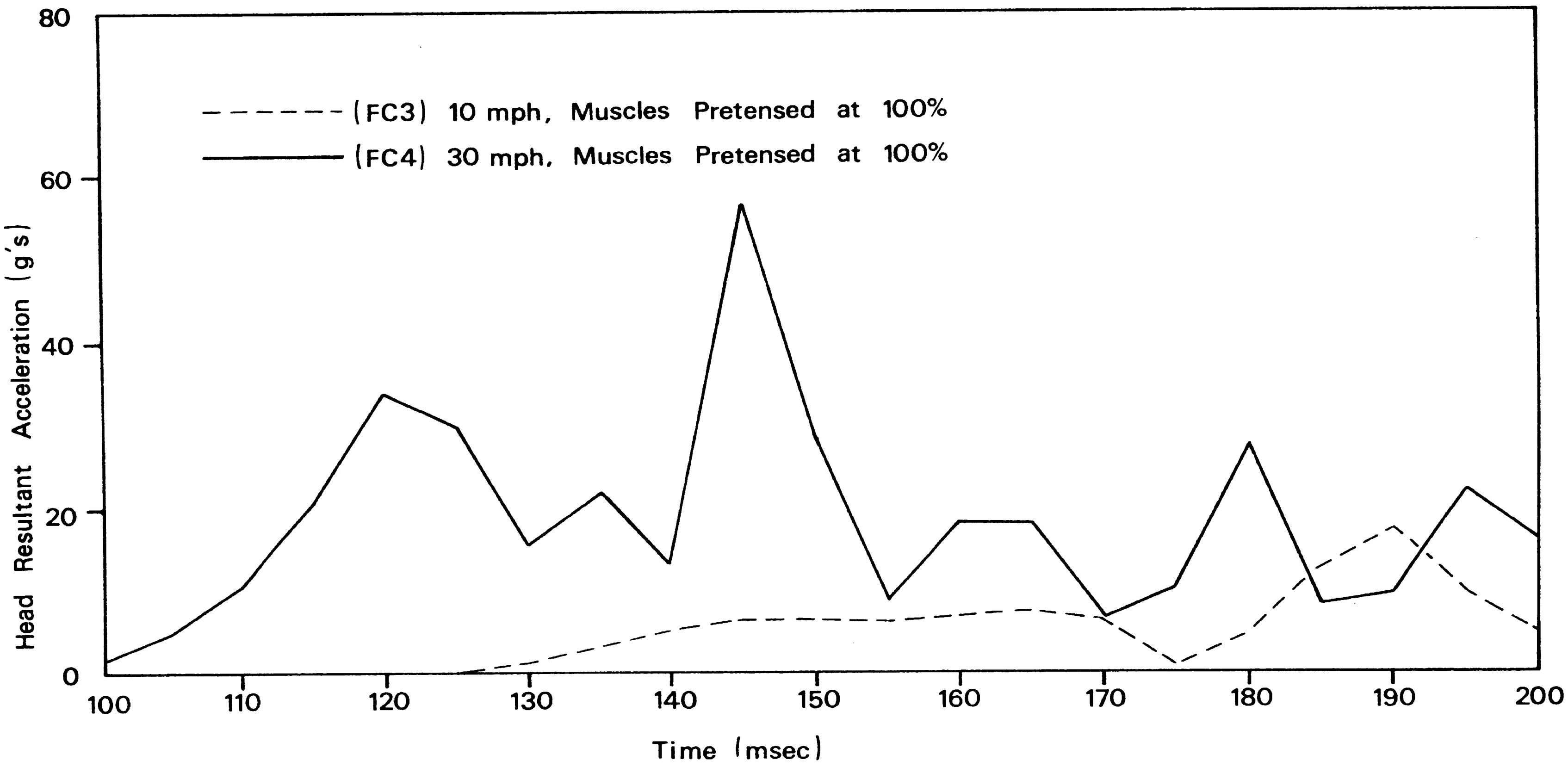


Figure 4.13 Head resultant acceleration for females, 62-74 years.

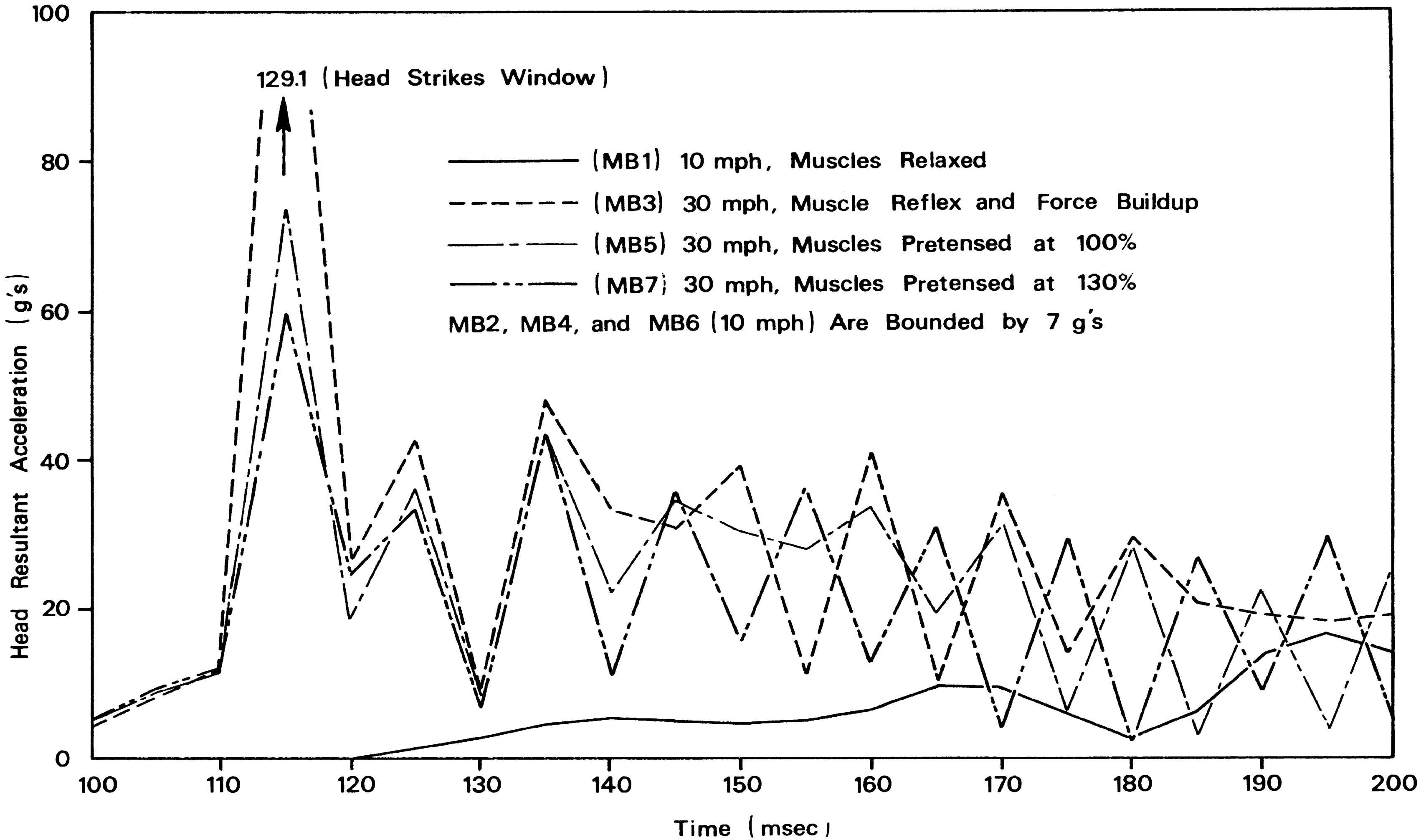


Figure 4.14 Head resultant acceleration for males, 35-44 years.

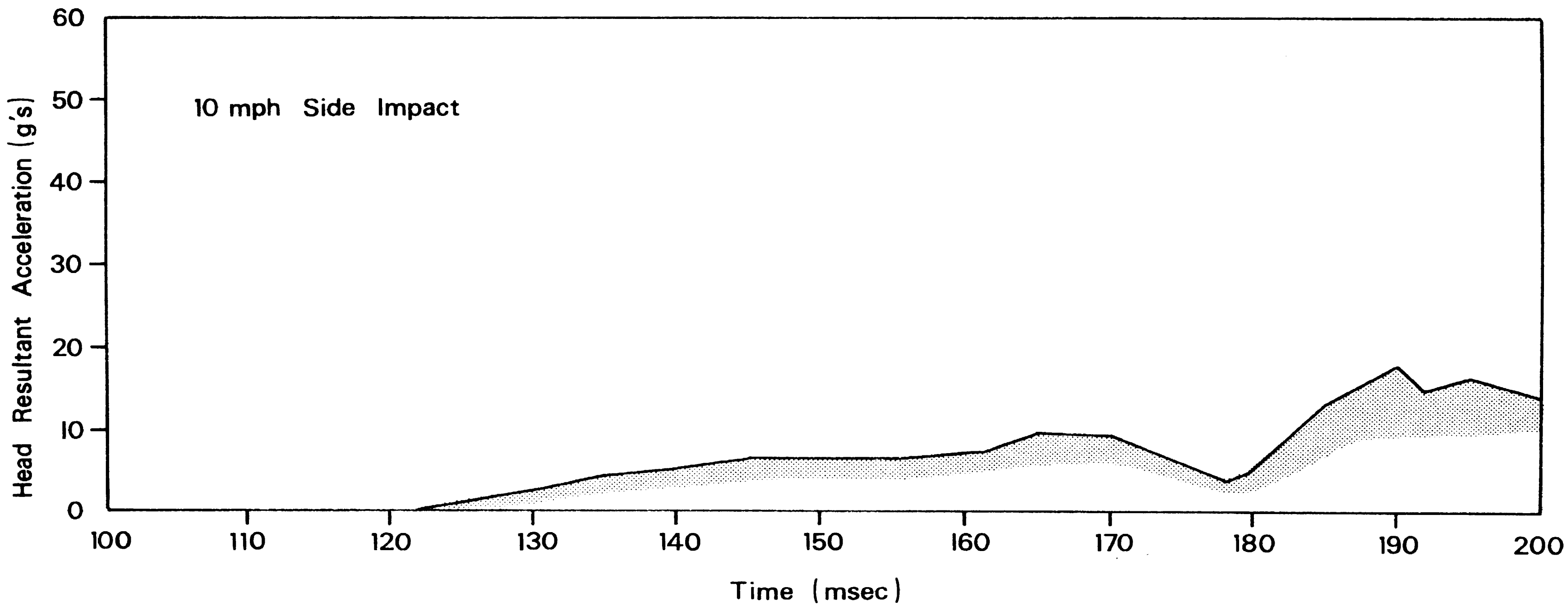


Figure 4.15 Head resultant acceleration, IIHS population (10 mph side impact).

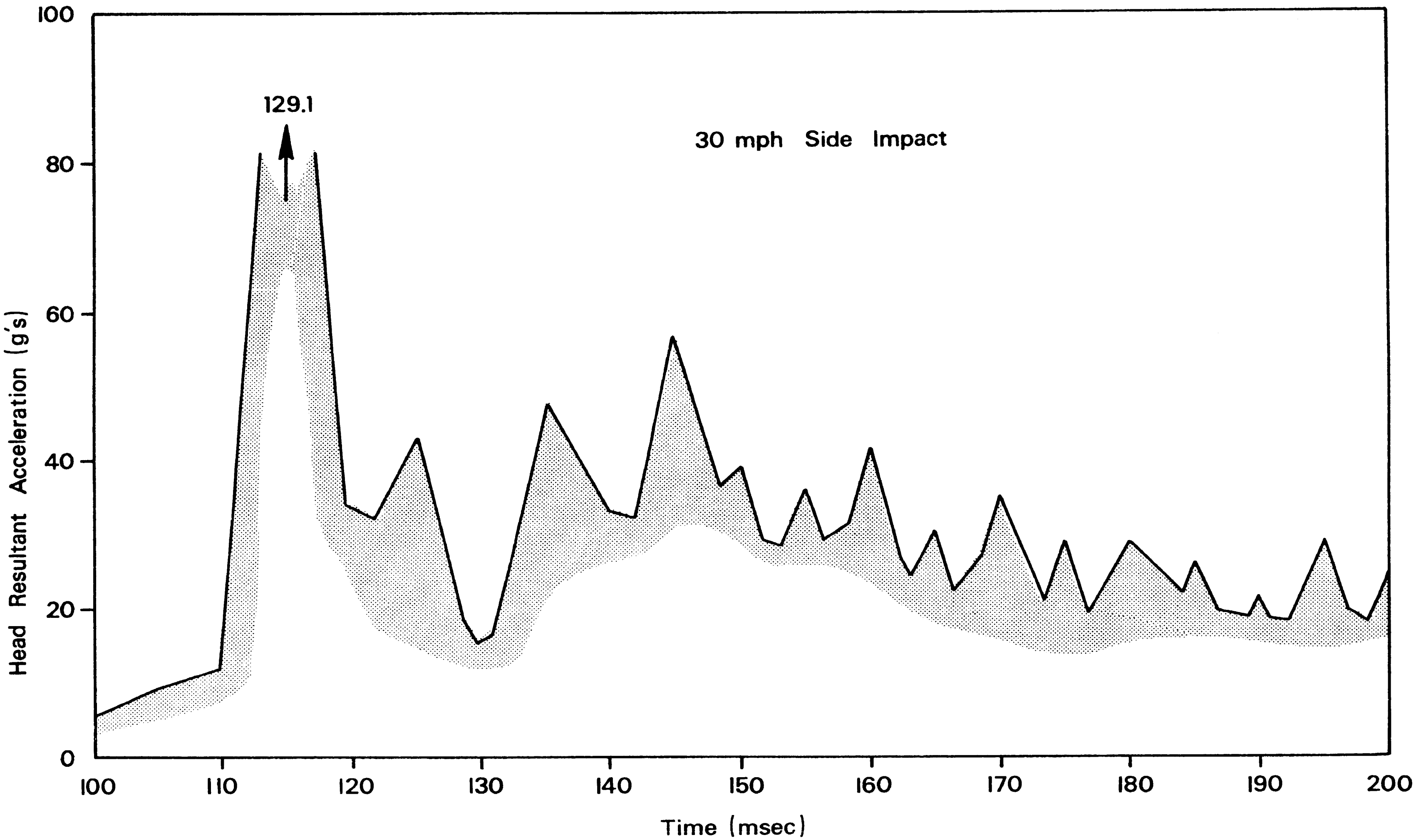


Figure 4.16 Head resultant acceleration, IIHS population (30 mph side impact).

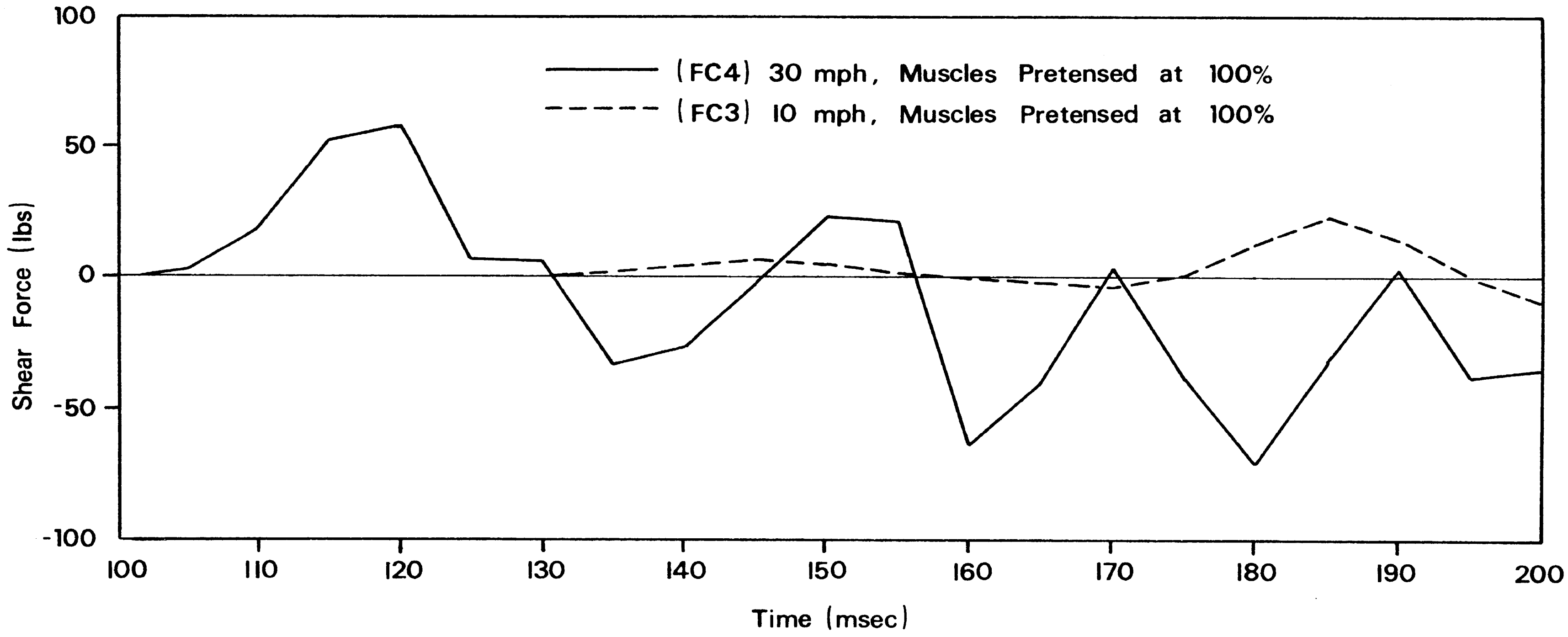


Figure 4.17 Shear force at occipital condyles for females, 62-74 years.

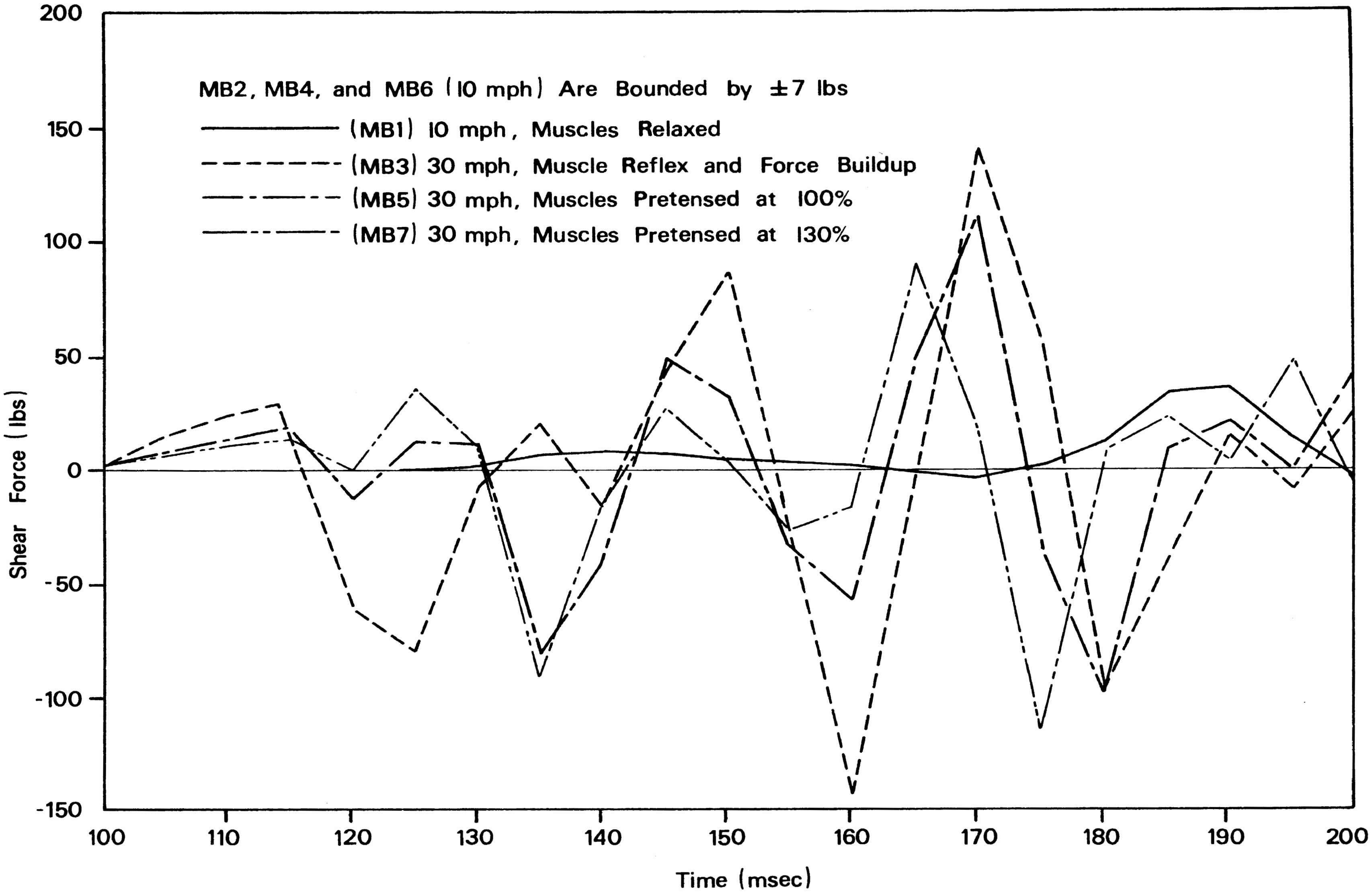


Figure 4.18 Shear force at occipital condyles for males, 35-44 years.

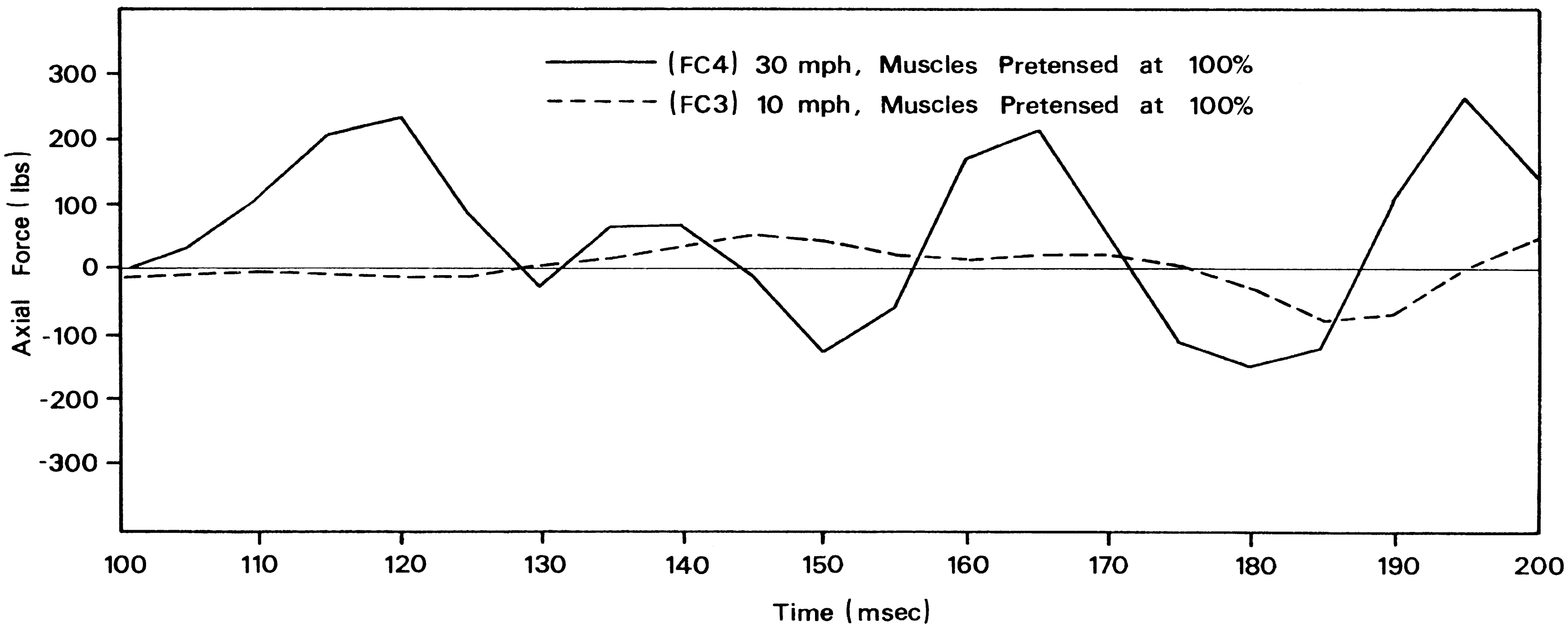


Figure 4.19 Axial force at occipital condyles for females, 62-74 years.

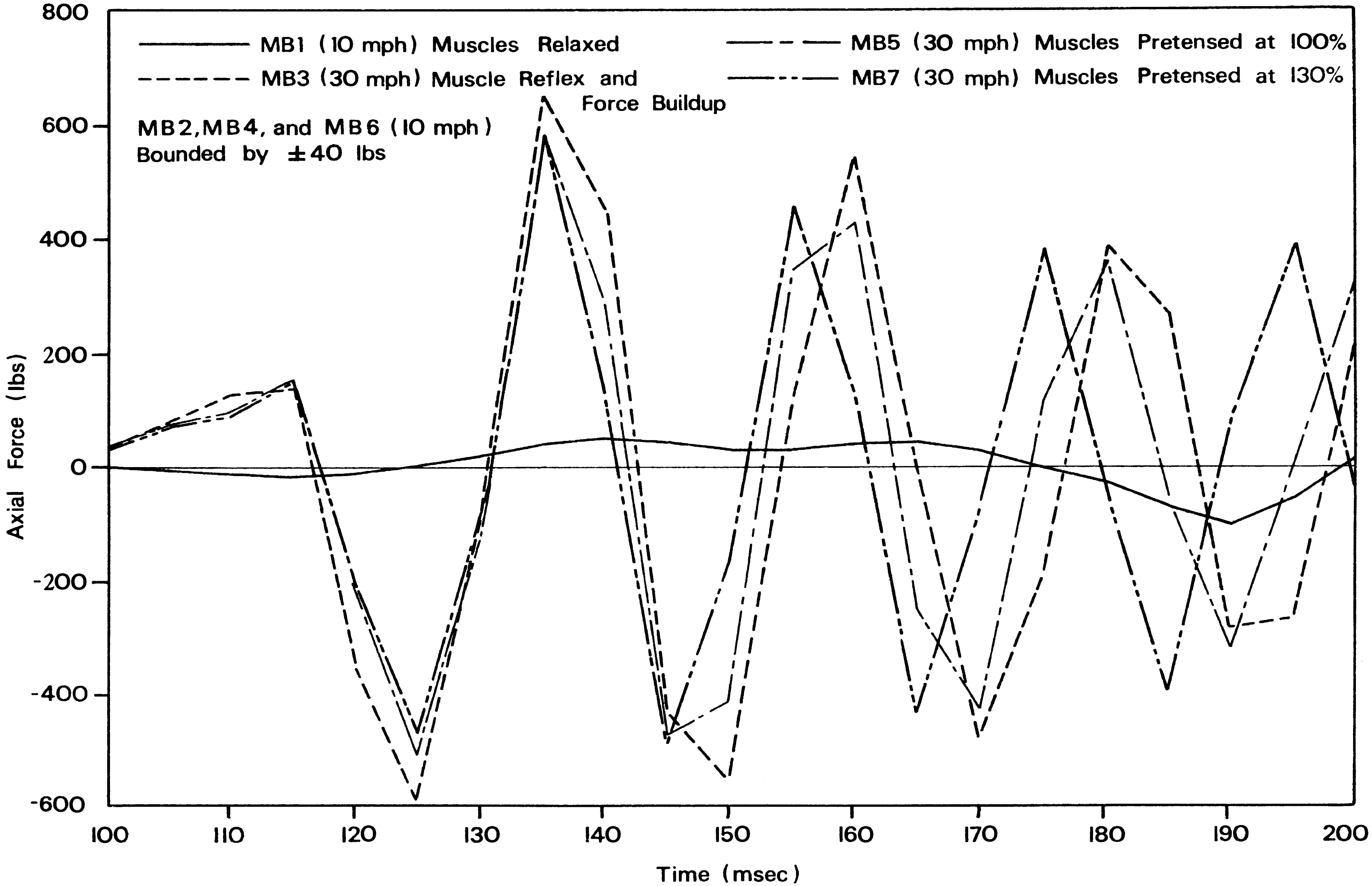


Figure 4.20 Axial force at occipital condyles for males, 35-44 years.

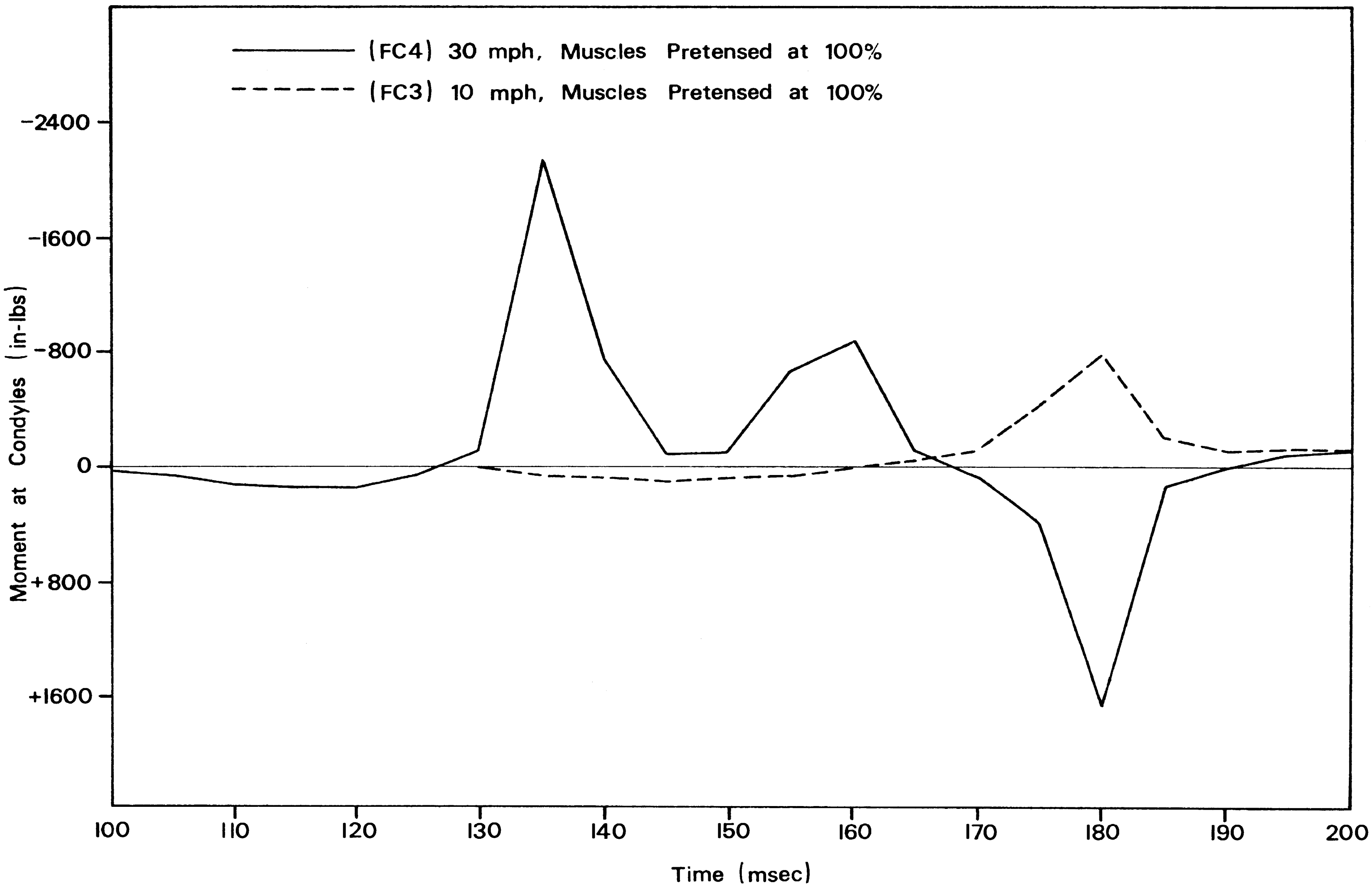


Figure 4.21 Moment at occipital condyles for females, 62-74 years.

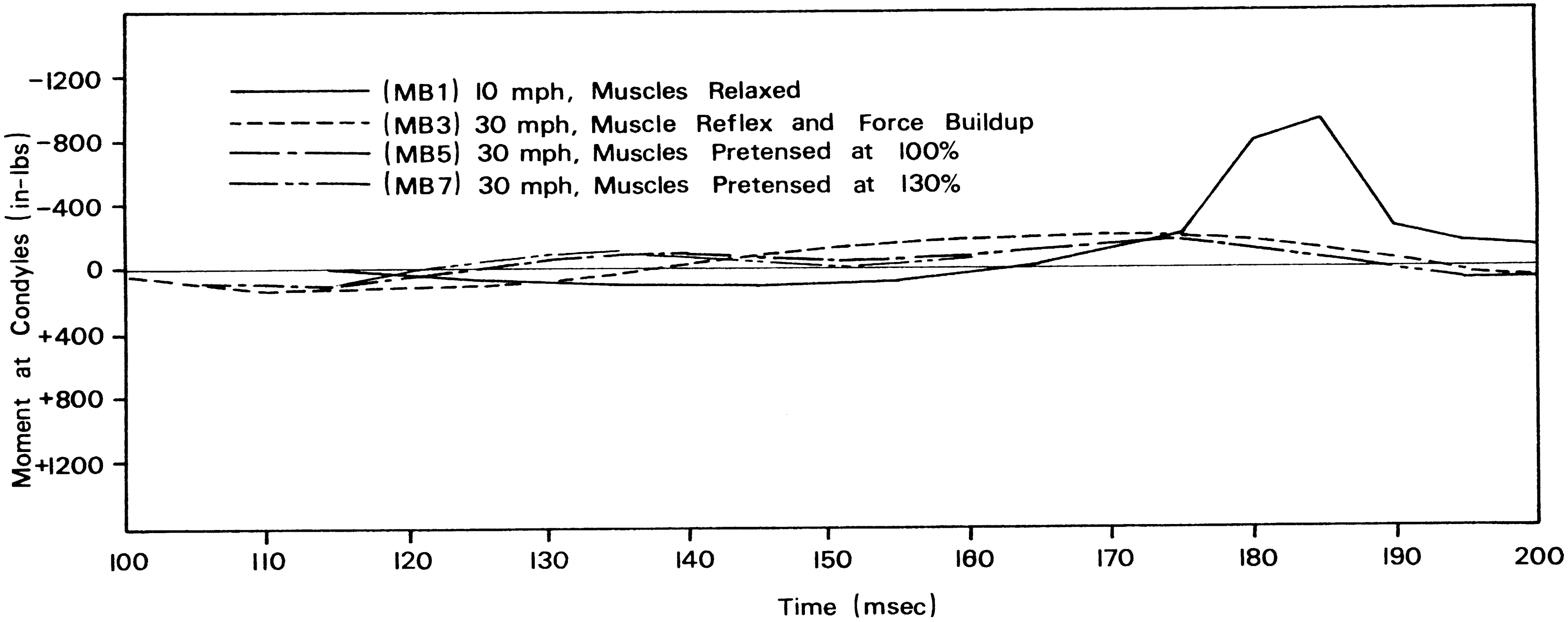


Figure 4.22 Moment at occipital condyles for males, 35-44 years.

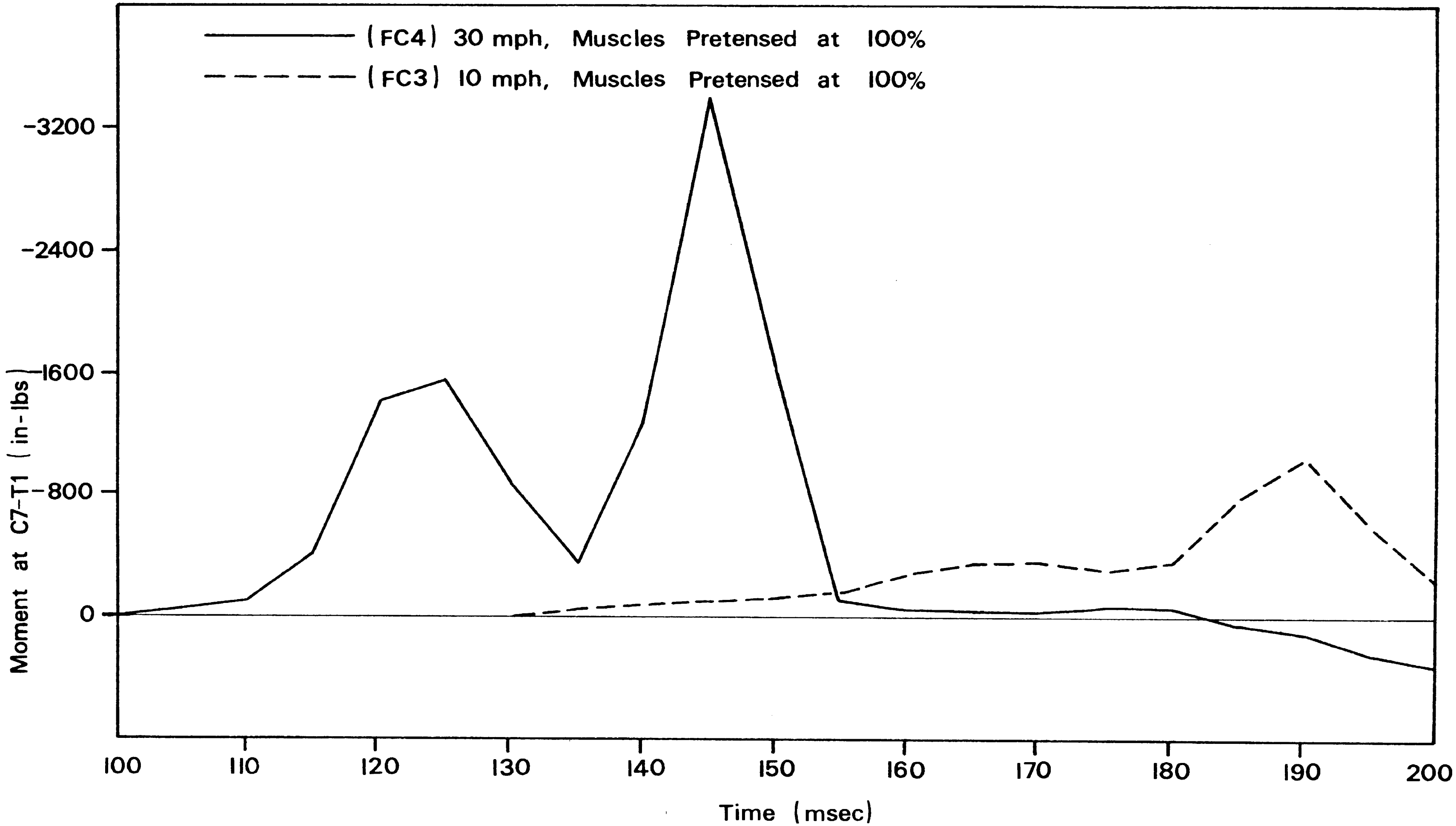


Figure 4.23 Moment at seventh-cervical/first-thoracic articulation for females, 62-74 years.

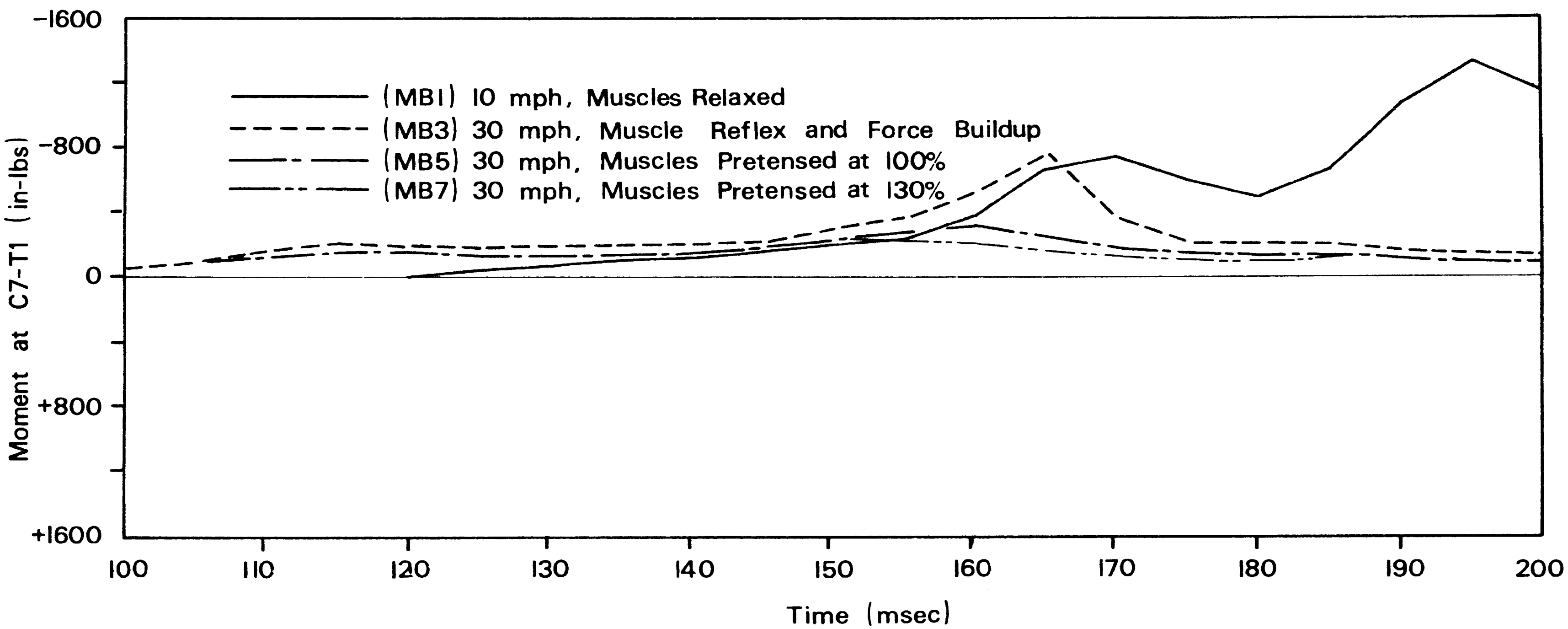


Figure 4.24 Moment at seventh-cervical/first-thoracic articulation for males, 35-44 years.

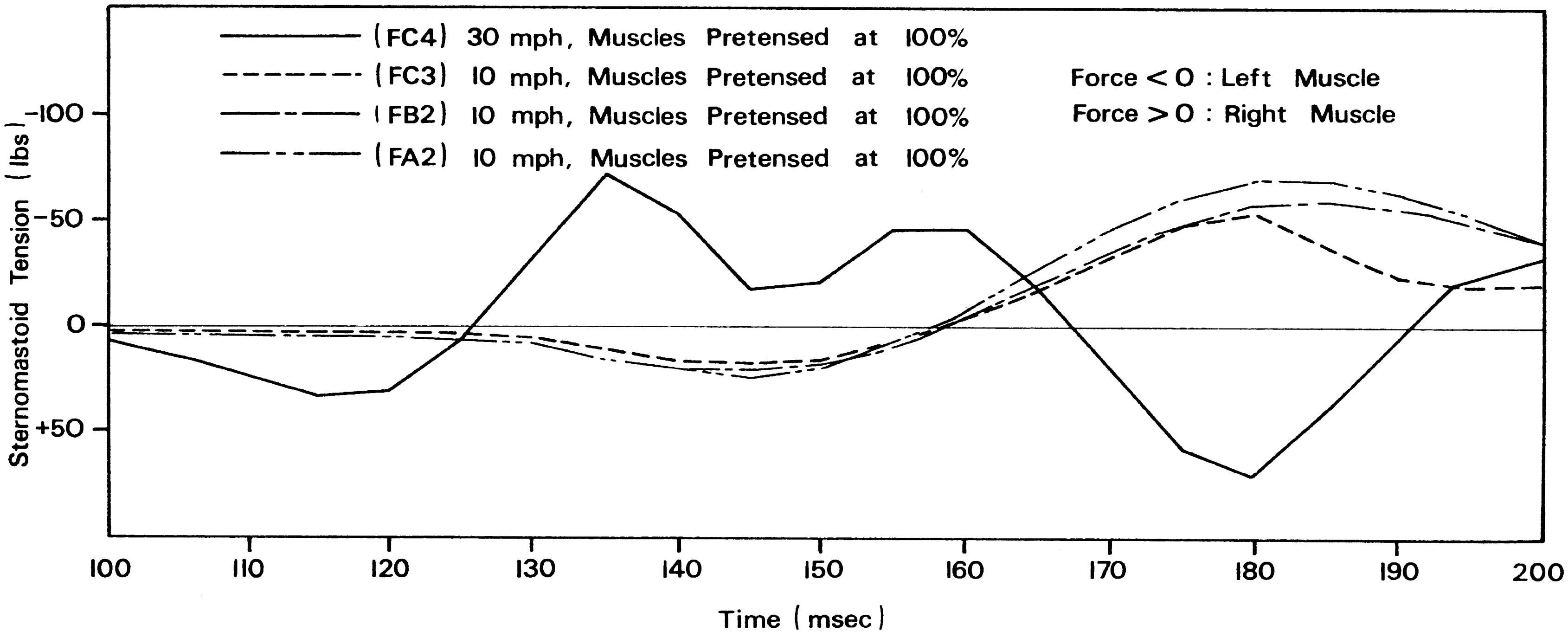


Figure 4.25 Tension in sternomastoid muscle group for females.

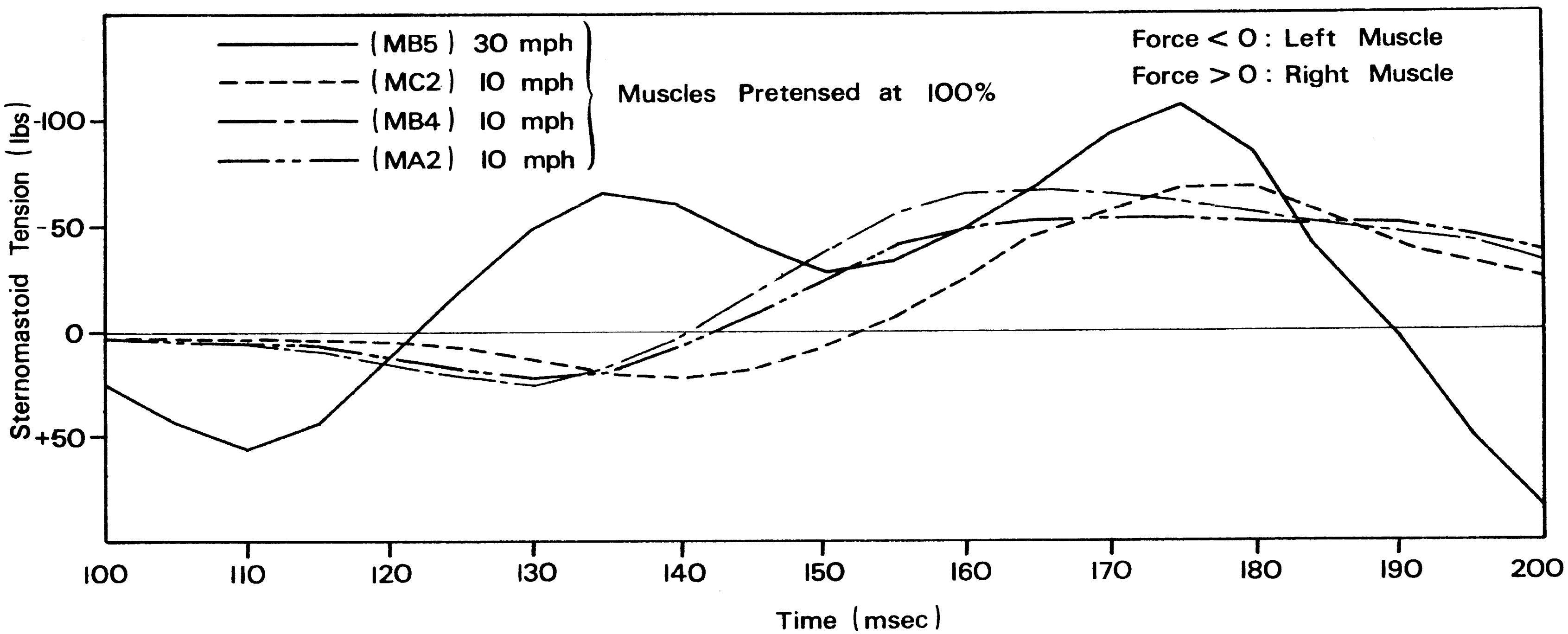


Figure 4.26 Tension in sternomastoid muscle group for males.

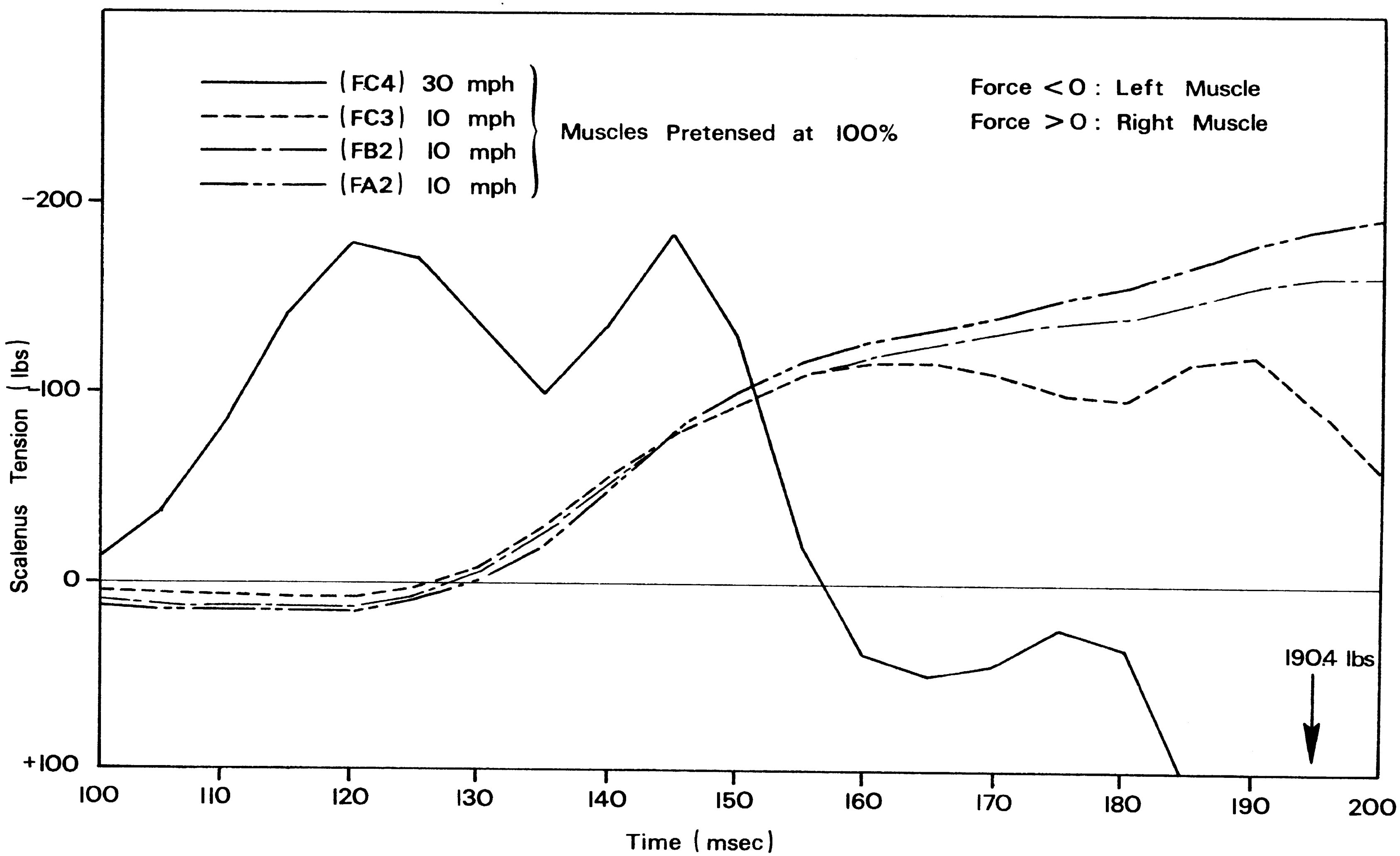


Figure 4.27 Tension in scalenus muscle group for females.

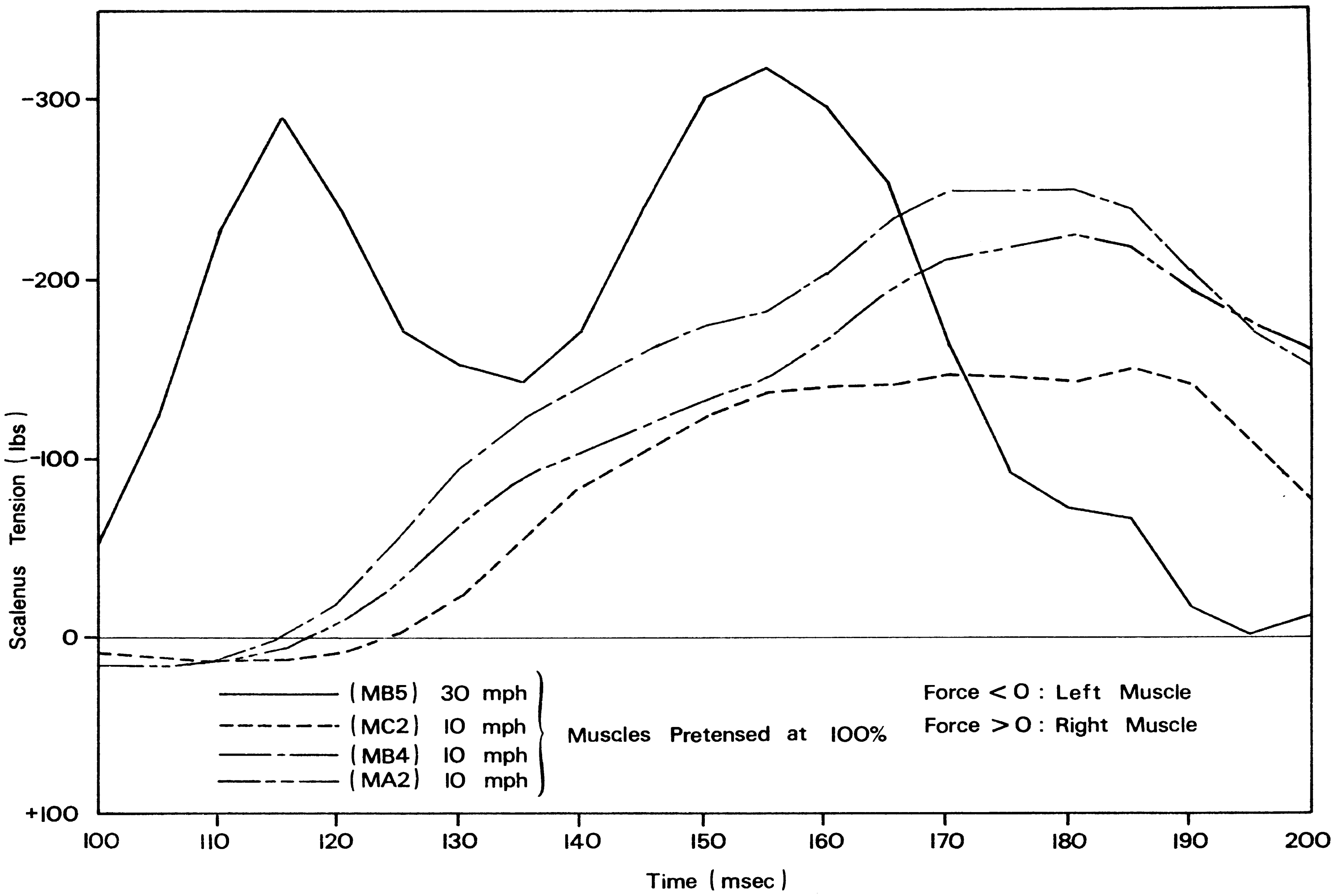


Figure 4.28 Tension in scalenus muscle group for males.

CHAPTER 5

DISCUSSIONS AND SUGGESTIONS

A. Overall Success of Study

The accomplishments of this study have gone far beyond the initial objectives. At the outset, it was proposed to essentially reproduce the sagittal plane study in the lateral motion plane. That is, the goals were to determine reflex times, strengths, and planar range of motion in the lateral plane for subjects grouped by age, sex, and stature; and to obtain measures of traditional anthropometry of subjects in order to describe the subject population, match it to those of previous studies, and to obtain various neck measurements which may correlate with the physical properties measured. Largely because of the adaptation of 3-dimensional orthogonal photogrammetry to this study, these initial goals were expanded to:

1) Obtain 3-dimensional range of motion described in Euler angle notation for all planar and three compound movements.
2) Obtain anthropometry from photogrammetry which would describe the seated automobile occupant.

In addition, the decision to accurately measure the angular and linear acceleration of the head using an arrangement of 4 accelerometers provided the ability to compare the neck jerk test results with impact tests of other investigators. This also allowed for comparisons with and improvements to the MVMA-2D computer simulation model in side-impact analyses.

B. Anthropometry

A large quantity of significant new anthropometric data has been produced as a result of this study. The sample size of 96 persons, subdivided into six categories of 16 each, provides enough data per category to perform reasonably powerful statistical analyses. In particular, the data from elderly subjects have not been available prior to the present work.

The technique of orthogonal photogrammetry has proven to be useful in obtaining specialized anthropometry. The location of the body landmarks of interest and the difficulty of a subject's maintaining the "normal" seated posture would have made the seated-position data virtually impossible to obtain with traditional methods. However, the technique as applied to anthropometry does have some limitations. First, the contours of the body are so complex that not all landmarks can be seen with three cameras placed at right angles to each other. The use of five cameras (front, back, both sides, and overhead) would still not completely eliminate the problem, since some important landmarks, such as tragion, are located in depressions of the body. (In the present study, this problem with tragion necessitated the taking of an additional photograph, with the head rotated 45 degrees, so that tragion could be located with respect to the headpiece and translated back to neutral position.) Second, great care must be taken to align the cameras so that they are exactly 90 degrees to one another and all camera axes intersect at a common origin in space. Third, the field of view tended to be somewhat restricted, since telephoto lenses were necessary to obtain sufficient magnification of the head to differentiate between the many desired landmarks. This prevented photographing the pelvic area. The use of another technique called stereophotogrammetry, which uses closely spaced cameras rigidly mounted to the same fixture to take stereoscopic photos, minimizes the first two problems. The equipment, however, is extremely expensive--many times the cost of an orthogonal system.

This study has also demonstrated that photogrammetric and traditional anthropometry techniques are not mutually exclusive but may be successfully blended to produce complementary data. Figures 3.1 through 3.6 were compiled from both types of measurements, and, even though mean values were used for each landmark location, the figures look reasonably like seated persons.

The anthropometry results in Appendix B have many potential applications. The seated-position data would be helpful to designers of human analog devices (computerized models and test dummies) as initial position guidelines for body landmarks. The method of data presentation allows average dimensions to be obtained to compare a wide variety of body landmarks for their dimensional relationships to one another. The correlation tables, combined with the Appendix B data, would permit body proportionality studies to indicate how reliably one body dimension may be used to predict another dimension. Also, these data (particularly for young subjects) may be compared to other comprehensive studies of anthropometry that have been conducted with military personnel. Anthropometry of Air Force Women (Clauser et al., 1972) is an example of a study from which many comparisons could be made.

Estimation of body mass and inertial properties for a generalized population may be possible with these data. No attempt was made to take enough measurements to precisely locate the position on a link at which the circumference was taken (for example, the point along the length of the humerus at which upper arm circumference was taken). However, Figure 2.10 demonstrates that it is not difficult to make estimates of these locations which produce a reasonable facsimile of a human. It remains to perform a sensitivity study, using these data in a whole-body mathematical model, to determine how critically placement of body masses affects predicted response.

The anthropometric data related to mass and inertial properties were taken so they could be used in or adapted to several modeling techniques. The limb lengths were taken as external dimensions compatible with measurements required for Dempster's (Dempster et al., 1964) regression equations to estimate link-to-link lengths. Also, the circumferences were taken in the standing position to be compatible with the requirements of three-dimensional lumped-mass models, such as those described by Bartz (1973) and Hanavan (1964). The feasibility and methods of adapting standing-position data to the seated position for crash victim simulations have not been adequately determined. This remains an area for possible future research that could make additional use of these data.

C. Range of Motion

By using the technique of three-dimensional photogrammetry to compute Euler angles of range of motion, not only the planar ranges of motion but the deviations from these planar movements are obtained. In the present study, for example, it was found that most subjects performed some head rotation while attempting to perform a lateral bend and that this rotation was usually to the right for right lateral bend and to the left for left lateral bend. For some individuals, especially in the elderly groups, it was even difficult to perform a pure flexion or extension without some substantial amount of head rotation (even when asked to repeat the movement) and this was apparent in the yaw angle for these subjects during flexion or extension.

In addition, this technique provides the ability to describe the total range of motion for the combination movements consisting first of rotation and then bending in some other direction. The three compound movements analyzed in this study are but a start in the task of describing the complete range of motion of the head and neck. For these and other complex movements, it must be noted that the values of the Euler angles are based on an assumption about the order in which they occurred. Thus, during left rotation plus bending toward the left shoulder, it is assumed that the order of the movements is yaw, pitch, and roll. This, of course, is a limitation to the use of Euler angles, since the second movement (bend toward the left) may be a rotation about some axis other than the pitch or roll axes (i.e., pitch and roll occur simultaneously), while in fact the values of the Euler angles assume that pitch occurred prior to roll. While the computation of Euler angles from orthogonal photogrammetry provides a means of describing head movement in space during actual impact testing, the necessity to specify an order to the Euler angles is again a limitation to the technique, since it is very unlikely that the movements will be purely planar in a real situation.

Tables 5.1 and 5.2 show comparison of the mean planar ranges of motion of this study with those of Ferlic (1962) for similar age groups

Table 5.1

Comparison of Range of Motion Results with Data from Ferlic (1962) MALES			
Age	sagittal	lateral	rotational
18-24 / 15-24	129.0 / 133.0	86.3 / 80.0	149.5 / 147.0
35-44 / 35-44	102.7 / 115.0	73.0 / 62.0	127.1 / 132.0
62-74 / 62-74	76.6 / 101.0	48.8 / 43.0	113.9 / 101.0

Table 5.2

Comparison of Range of Motion Results with Data from Ferlic (1962) FEMALES			
Age	sagittal	lateral	rotational
18-24 / 15-24	124.0 / 148.0	86.3 / 82.0	150.6 / 154.0
35-44 / 35-44	104.6 / 121.0	73.0 / 74.0	143.6 / 141.0
62-74 / 62-74	84.3 / 123.0	56.3 / 70.0	123.6 / 130.0

Note: Upper half= lateral neck study
Lower half= Ferlic study
All measures in degrees

and males and females, respectively. For many groups there is excellent agreement between the two studies, while for others the differences are substantial. The greatest disagreements are found for the sagittal plane and for the elderly subject groups. The latter may be due to small sample sizes (e.g., Ferlic's data are for 3 males and 3 females, age 62-74). The reasons for differences in the sagittal plane results are not so apparent, but two possibilities should be mentioned.

The first is a consequence of the fact that the "stops" for range of motion are not solid limits, and, therefore, subject motivation is an important factor in determining how far the subject will voluntarily move. A subject, when highly motivated, will try harder and achieve a greater extension than when poorly motivated. While subjects were requested to move as far as they were able, it is difficult to measure or change their motivation to do this. In particular, for extension, the fear of possible neck strain or injury may reduce the voluntary effort.

The second factor which must be considered is the amount of torso movement. As mentioned in Chapter 2, subjects were asked to perform all head and neck movements without moving the shoulders and torso. Subjects were watched carefully and when any torso movement did occur the subject was asked to repeat the movement. Thus torso movement was minimized in the present study and this could also account for the lower values of range of motion. Furthermore, it is possible that the restriction of subject torso movement caused subjects to be more cautious and less able to push against the "stops," thereby resulting in smaller ranges of motion.

D. Reflex Tests

Perhaps the most unexpected finding from the reflex time tests was that the times for the sternomastoid muscles were significantly smaller for lateral head jerks than for the sagittal plane jerks (extension) of the previous study (lateral study average = 50.2 msec., sagittal study average = 71.7 msec., see Table 3.23). The reason for this difference may be a difference in rate of muscle stretch for the head jerks in the two directions. If, for example, the sternomastoid muscle is oriented such that it is stretched at a greater rate (i.e., it receives a greater percentage of stretch in the same period of time) during lateral bend than during extension, then the initiation of impulses from a sufficient number of muscle spindles to cause a "measurable" EMG signal will occur sooner for lateral bend than for extension.

While the results of Chapter 4 indicate that even the shorter reflex times for lateral bend may be too long to prevent neck injury during surprise impacts, it is interesting that the reflex times for lateral bend are shorter than for extension, and the range of motion is less. In fact, the average lateral reflex time is 70 percent of the average extension reflex time (50.2 msec./71.7 msec.), and the average lateral range of motion is 66 percent of the average extension range of motion ($35.6^\circ/54.2^\circ$). Thus, there may be some functional significance to these shorter lateral bend reflex times.

E. Correlations

In addition to the correlations of anthropometry results reported on in Chapter 3, an extensive correlation analysis was run on all the results to determine if any significant relations exist between anthropometry measures, ranges of motion, reflex times, and muscle strengths. While it might be suspected and has been suggested by Ferlic (1962) that certain correlations exist, no significant ($R>.707$) correlations were observed in the present study. There was, for example, no correlation between range of motion in any plane and stature, the contrived measure of posterior neck length, or any other anthropometric measurement and no significant correlation between strength and stature or weight. In the previous sagittal plane study there was also no correlation between stature and any physical property of the neck. This resulted in the decision to consider stature as a secondary variable and thereby reduce the needed sample size. That decision is further justified by the results of this study.

F. Suggestions for Future Work

From an engineering point of view, the human neck and cervical vertebrae form a fascinating and complex structure which provides, in normal persons, both extreme flexibility and rigid support, while at the same time protecting the vital but vulnerable spinal cord at a most critical level. While the present studies have had a significant contribution to our understanding of some of the physical properties of the neck related to age, sex, and stature of the individual, there is much work to be done.

In the reflex tests of the present studies, the head was jerked by a force applied near the head center of gravity. A similar type of experiment where the jerk or force is applied to the torso would be beneficial in further validating models and would be a more "realistic" technique for determining reflex times relative to impact. In this regard the relatively high-G sled tests of human volunteers (e.g., Ewing and Thomas, 1971, 1972, 1973; Patrick et al., 1970) provide the means for improving our understanding of the human neck and its susceptibility to injury. These tests, however, are necessarily performed on a select population (young military volunteers). By combining data from the present studies with data from these sled tests, an extrapolation of high-G sled test results to the general population may be possible.

The present study has shown (as have others) that range of motion becomes more limited with age. A consequence of this is greater susceptibility to tissue injury during whiplash. Questions remain, however, concerning what tissues are limiting the range of motion and are therefore more susceptible to injury, and as to what methods might be used to detect highly susceptible persons or even prevent injuries to individuals with particularly high susceptibility ratings.

As pointed out in Section C of this chapter, there are limitations to the use of Euler angles for describing range of motion. The development of a 3-dimensional range-of-motion scheme which would be independent of the order of rotations would be extremely useful for computer modeling and for standardizing range of motion reporting procedures. Such a scheme is essential, it seems, for a comprehensive analysis of head and neck range of motion to be performed and the data used in three-dimensional crash simulation models.

Finally, the data reported on in this report lead to a need for more precise and extensive correlations of injury statistics with the age, sex, and anthropometry of individuals. These statistics would be most interesting in light of the present results and would be useful in validating the predictions of existing computer models.

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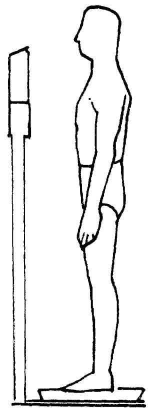
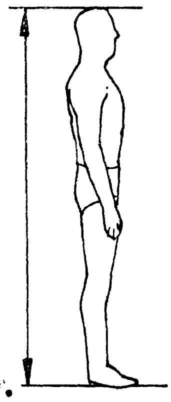
APPENDIX A

DESCRIPTION OF ANTHROPOMETRIC MEASUREMENTS

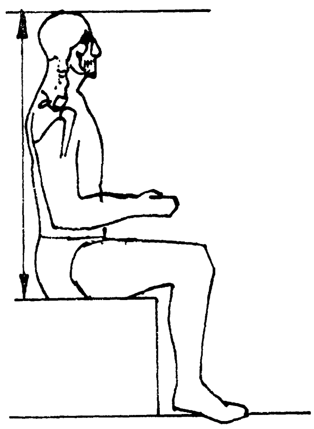
I. General Body Measurements



1. Weight - Taken on standard medical-type scale to nearest one-half pound. Subject clothed in shorts and sleeveless top, the weight of which is deducted from weight of subject.



2. Stature - The subject maintains an erect standing posture, feet together, arms hanging at side, looking straight ahead with head held in Frankfort Plane* which is determined by lining up the infraorbital margins with tragion in the same horizontal plane. The vertical distance is measured with the wall-mounted anthropometer from the floor to vertex (the highest point on the subject's head) with the anthropometer blade firmly contacting the scalp.



3. Erect Sitting Height - The subject sits erect with arms hanging at sides and forearms at a 90° angle to upper arms, hands extended, looking straight ahead with head held in Frankfort Plane, which is determined by lining up the infraorbital margins with tragion in the same horizontal plane. Lower legs are at right angle to upper legs. The vertical distance is measured with an anthropometer from the sitting surface to vertex, with the anthropometer arm firmly touching scalp.

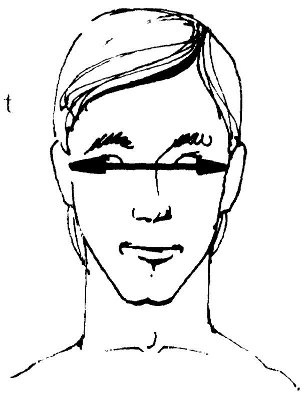
*See attached glossary (Section VII) for all technical terms underlined in the measurement descriptions.

II. Head Measurements

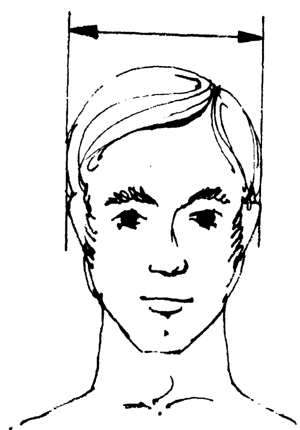
4. Head Circumference - The subject is seated in a relaxed posture. The maximum circumference of the head is measured with a steel tape passing over glabella and held perpendicular to the midsagittal plane (but not necessarily horizontally).

5. Bennett Ellipse Circumference - The subject is seated in a relaxed posture. The head circumference is measured with a steel tape passing over menton and a point on back of head at maximal distance.

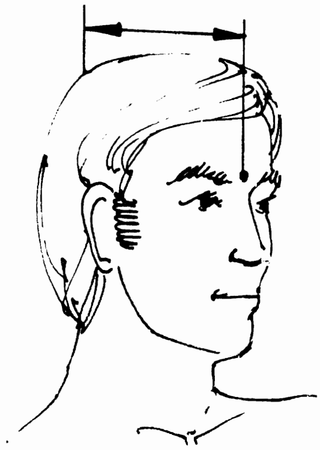
6. Bitragion Diameter - The subject is seated in a relaxed posture. The diameter between right and left tragion is measured with the spreading calipers.



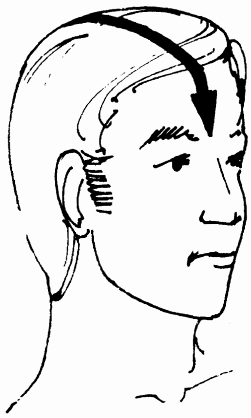
7. Head Breadth - The subject is seated in a relaxed posture. The maximum breadth of the head is measured with the spreading calipers perpendicular to mid-sagittal plane of the head.



8. Head Length-The subject is seated in a relaxed posture. The maximum length of the head is measured with the spreading calipers from glabella to the occipital region in the mid-sagittal plane of the head.

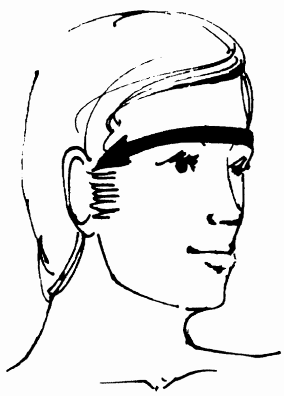


9. Sagittal Arc Length- The subject is seated in a relaxed posture. The arc length is measured with the steel tape in the mid-sagittal plane of the head, from glabella to opisthocranion.

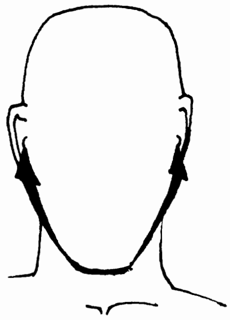


10. Coronal Arc Length- The subject is seated in a relaxed posture. The arc length is measured with the steel tape from right to left tragion over the top of the skull in a vertical plane.

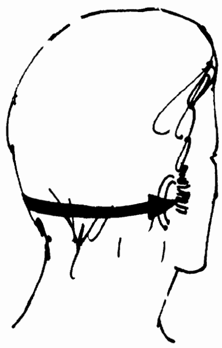
11. Bitragion-Glabella Arc Length- The subject is seated in a relaxed posture. The arc is measured with the steel tape from left to right tragion over glabella.



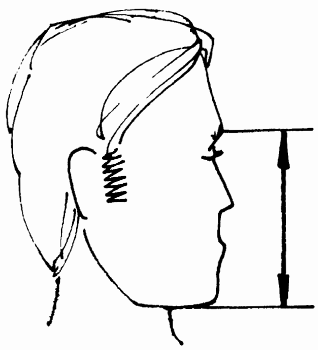
12. Bitragion-Menton Arc Length - The subject is seated in a relaxed posture. The arc length is measured with the steel tape from left to right tragion over menton.



13. Bitragion-Inion Arc Length - The subject is seated in a relaxed posture. The arc length is measured from left to right tragion over opisthocranion with the steel tape. The hair is compressed.

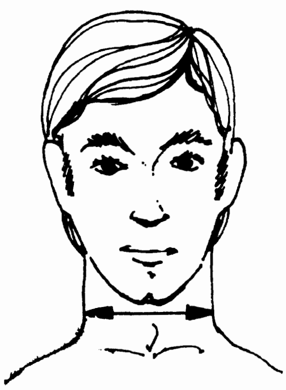


14. Facial Height - The subject is seated in a relaxed posture. The sliding calipers are used to measure the vertical distance from glabella to menton.

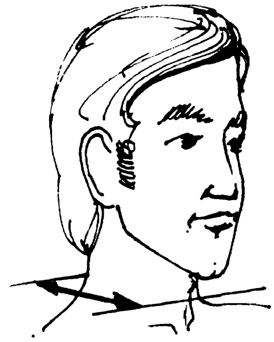


III. Neck Measurements

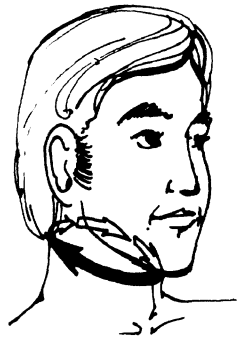
15. Lateral Neck Breadth - The subject is seated in erect posture, with head in Frankfort Plane. The breadth is measured from the rear at the mid-point of the neck, using the beam anthropometer.



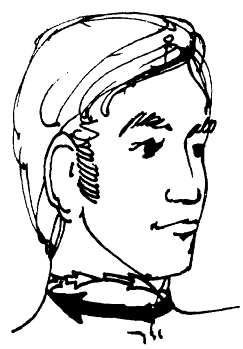
16. Anterior-Posterior Neck Breadth - The subject is seated in erect posture, head in Frankfort Plane. The breadth is measured with the beam anthropometer from left side of subject at the level of the inferior aspect of the Adam's apple.



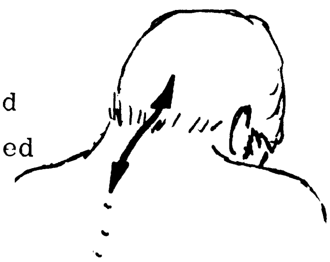
17. Superior Neck Circumference - The subject is seated in erect posture, with head in Frankfort Plane. The circumference is measured with the steel tape from rear of subject at the level of chin-neck intersect and just below opisthocranion.



18. Inferior Neck Circumference - Subject is seated in erect posture, with head in Frankfort Plane. The circumference is measured with the steel tape from rear of subject, from lowest anterior neck level at clavicale.

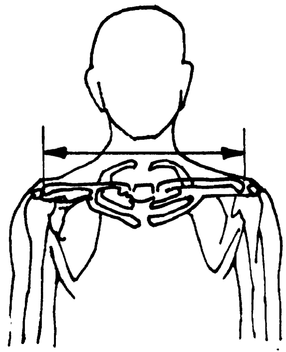


19. Posterior Neck Length - The subject is seated in erect posture. The surface distance is measured with the steel tape from cervicale to opisthocranion, with subject's neck fully flexed.

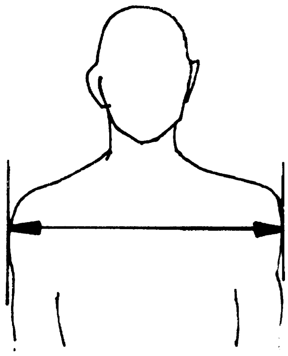


IV. Measurements to Determine Size and Location of Major Body Masses

20. Biacromial Breadth - The subject maintains an erect posture, with head in Frankfort Plane, upper arms resting against sides and forearms extended at a 90° angle to upper arms. The distance between right and left acromions is measured with a beam anthropometer from the rear.

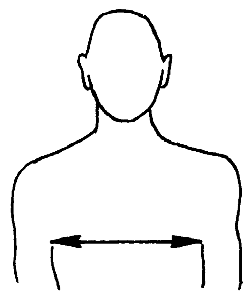


21. Shoulder Breadth (Bideltoid) - The subject sits erect with head in Frankfort Plane, upper arms resting against sides, forearms extended horizontally. The distance is measured with the beam anthropometer horizontally across the deltoid muscles.

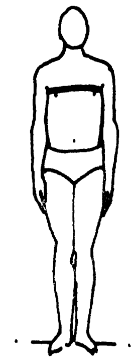


22. Chest Height (Axilla) - The subject stands in erect posture. The perpendicular height from the floor to the axilla is measured with the wall-mounted anthropometer. The measurement point on the body corresponds to the level at which chest circumference is measured.

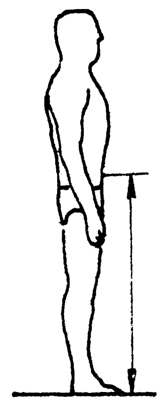
23. Chest Breadth - The subject stands in relaxed posture and lifts both arms in order to position anthropometer blades under the arms from front of subject. The arms are then lowered to the sides. The horizontal measurement is taken with the beam anthropometer at the level of the axilla. The measurement point corresponds to the level at which chest circumference is measured.



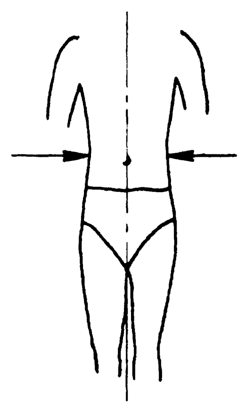
24. Chest Circumference - The subject maintains a relaxed posture and raises both arms to allow positioning of the steel tape in a horizontal plane around the chest at the axillary level. The arms are then lowered and the measurement is taken during normal breathing.



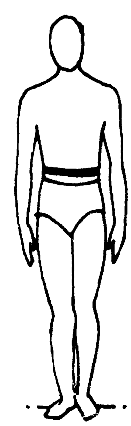
25. Waist Height (or Omphalion Height) - The subject stands in erect posture. The perpendicular height from the floor to omphalion is measured with the wall-mounted anthropometer. The measurement point on the body corresponds to the level at which waist circumference is measured.



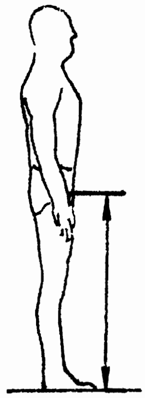
26. Waist Breadth - The subject stands in relaxed posture, weight distributed evenly on both feet. The horizontal breadth is measured with the beam anthropometer at the level of omphalion. The measurement point corresponds to the level at which waist circumference is measured.



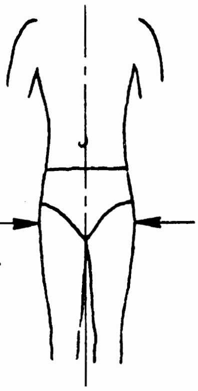
27. Waist Circumference - The subject stands in relaxed posture, weight distributed evenly on both feet. With a steel tape held in the horizontal plane, the measurement is taken at the level of omphalion. The reading is made at the average point of quiet respiration. The subject is cautioned not to pull in the stomach.



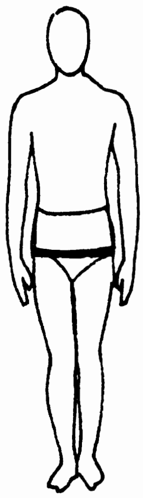
28. <u>Hip Height</u> (or Height at Maximum Posterior Protrusion of Buttocks) - The subject stands in erect posture. The perpendicular height from the floor to the hip landmark (maximum posterior protrusion level) is measured with the anthropometer. The measurement point on the body corresponds to the level at which hip circumference is measured.



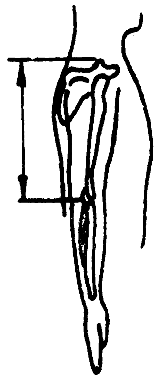
29. <u>Hip Breadth (Standing)</u> - The subject stands in a relaxed posture with the weight distributed evenly on both feet. The horizontal breadth is measured with the beam anthropometer at the level of the maximum posterior protrusion of the buttocks. This corresponds to the level at which hip circumference is measured.



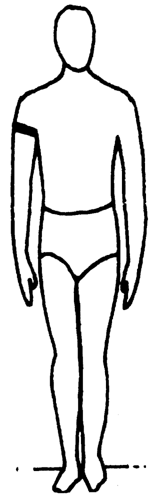
30. <u>Hip Circumference (through clothes)</u> - The subject stands in a relaxed posture, looking straight ahead, heels together, weight distributed evenly on both feet. The horizontal circumference is measured with a steel tape passed around the hips without constriction, at the level of the maximum posterior protrusion of the buttocks.

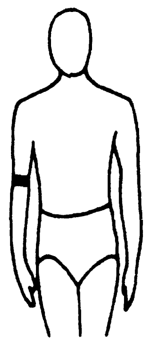


31. Acromion-Radiale Length - The subject stands in relaxed posture. With the right arm hanging freely at the side, the head of the radius is located by palpation. The parallel distance is measured with the beam anthropometer between right acromion and radiale.



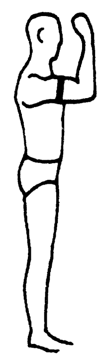
32. Upper Arm Circumference (at Axilla) - The subject maintains a relaxed posture and raises and lowers the right arm to allow horizontal positioning of the tape. The circumference is measured with a steel tape at the level of the axilla.



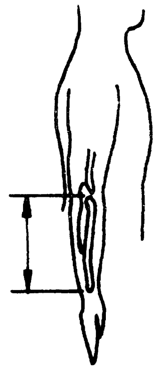


33. Upper Arm Circumference (above Olecranon) subject maintains a relaxed posture with arms hanging at sides. Measurement is taken with steel tape on upper arm just above the olecranon process.

34. Biceps Flexed Circumference - The subject maintains a relaxed posture with arms hanging freely at sides. The subject then flexes his right arm at least 90°, makes a fist while holding his upper arm horizontal to the floor, and flexes his biceps to the maximum. The measurement is taken with a steel tape at the maximum circumference of the upper right arm.

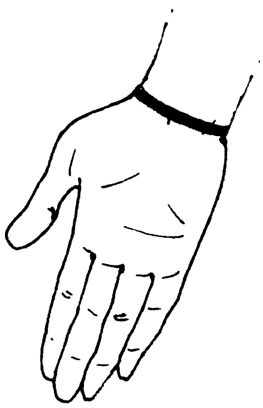


35. Radiale-Stylion Length - The subject is standing in relaxed posture. With the right arm hanging freely at the side, the head of the radius is located by palpation at the center of the skin dimple. The distance is measured with the beam anthropometer from radiale to stylion.

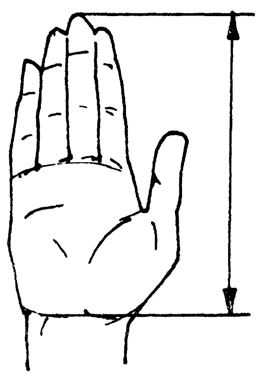


36. Forearm Circumference - The subject maintains a relaxed posture, with arms hanging freely at sides. The circumference of the right forearm is measured with a steel tape at its maximum circumference.

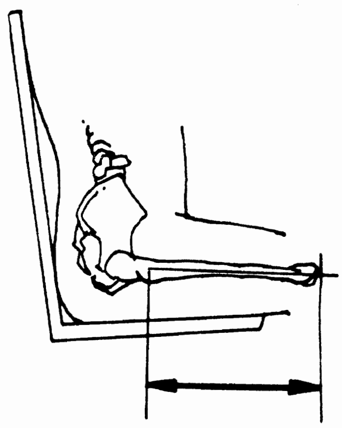
37. Wrist Circumference - The subject maintains a relaxed posture, with arms hanging freely at sides. The right wrist circumference is measured with a steel tape at the distal wrist crease.



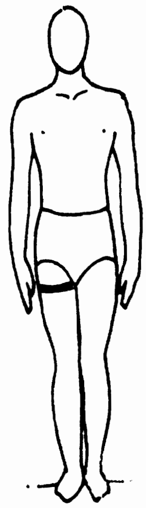
38. Hand Length - The subject's hand is extended with the palm up. The distance from the proximal edge of the navicular bone at the wrist to the tip of the middle finger is measured with a sliding caliper.



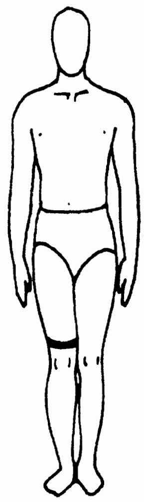
39. Trochanterion-Femoral Condyle Length - The subject is seated in relaxed posture. The distance is measured with the beam anthropometer from the most lateral point palpable on the greater trochanter of the right femur to the distal tip of the lateral condyle. To locate the latter point, the lateral epicondyle is palpated and pressure is applied distally until the most distal lateral tip is found and marked.



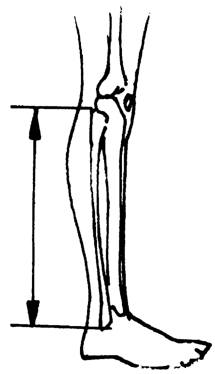
40. Upper Thigh Circumference - The subject stands in a relaxed posture, feet approximately 10 cm. apart, weight distributed evenly on both feet. A steel tape is held in a plane perpendicular to the long axis of the right thigh and the circumference of the thigh is measured at the level of the gluteal furrow.



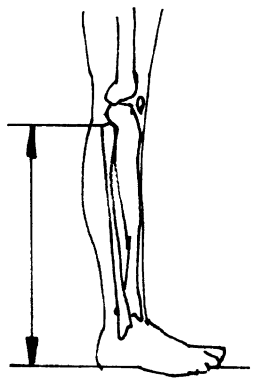
41. Lower Thigh Circumference - The subject stands in a relaxed posture, with heels together and weight distributed evenly on both feet. With the tape held perpendicular to the long axis of the right thigh, the circumference is measured at the level just above the top of the patella.



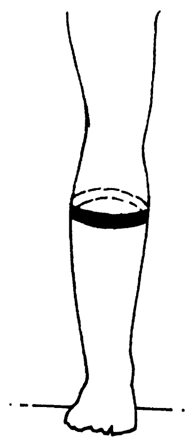
42. Fibula Length - The subject maintains a relaxed posture, but with legs straight, feet together and weight evenly balanced. A length parallel to the axis of the leg is measured with a beam anthropometer from right fibulare to the palpable distal tip of the styloid process.



43. Fibula Height - The subject maintains a relaxed posture, but with legs straight, feet together, and weight evenly balanced. The vertical distance is measured with the anthropometer from the floor to fibulare.

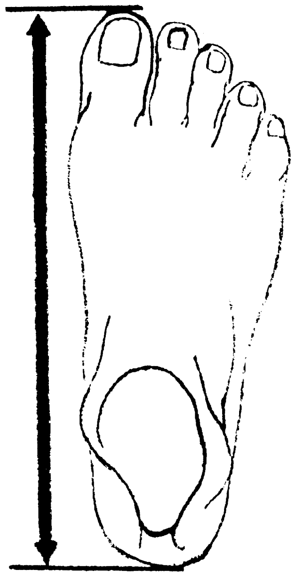


44. Calf Circumference - The subject stands in relaxed posture, with legs slightly apart. The right calf is measured with a steel tape at maximum circumference.

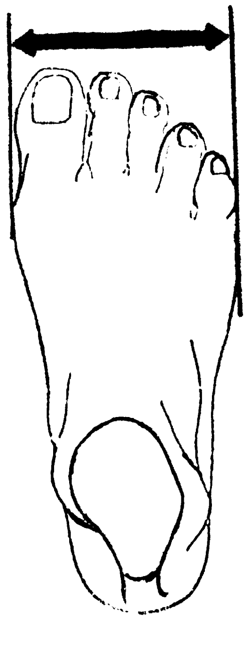


45. Ankle Circumference - The subject is standing in a relaxed posture, with legs slightly apart and weight distributed evenly on both feet. The minimum circumference is measured with a steel tape just superior to the lateral malleolus.

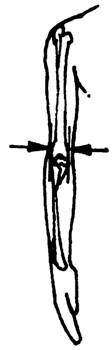
46. Foot Length - The subject stands in relaxed posture, with weight evenly distributed on both feet. The maximum length of the right foot is measured (with the beam anthropometer) from the back of the heel to the tip of the longest toe.



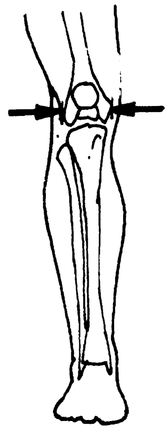
47. Ball of Foot Breadth - The subject stands in relaxed posture, with weight evenly distributed on both feet. The breadth of the right foot is measured (with the beam anthropometer) between the inner and outer balls of the foot (first and fifth metatarsal-phalangeal joints).



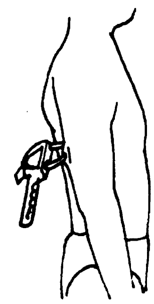
V. Measurements Related to Somatotypes



48. Humeral Biepicondylar Diameter - With the subject in a relaxed standing posture, the distance between the lateral and medial epicondyles of the right humerus is measured with a spreading caliper.

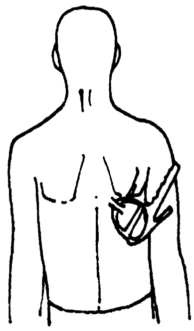


49. Femoral Biepicondylar Diameter - The subject stands in a relaxed posture with feet spread slightly apart. Using the spreading caliper, the horizontal distance is measured between the medial and lateral epicondyles of the right femur.

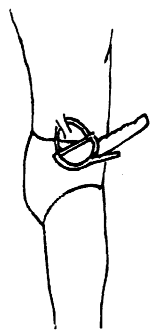


50. Triceps Skinfold - The measurement is taken on the dorsal aspect of the right arm, midway between the acromion and the tip of the elbow (olecranon) when the forearm is extended to hang freely. The Lange Skinfold Caliper is used. The skinfold is lifted parallel to the long axis of the arm by firmly grasping a fold between the thumb and forefinger about 1 cm. from the point to which the caliper is applied. A reading is made within 3 sec after application of the caliper, and the average is taken of several readings.

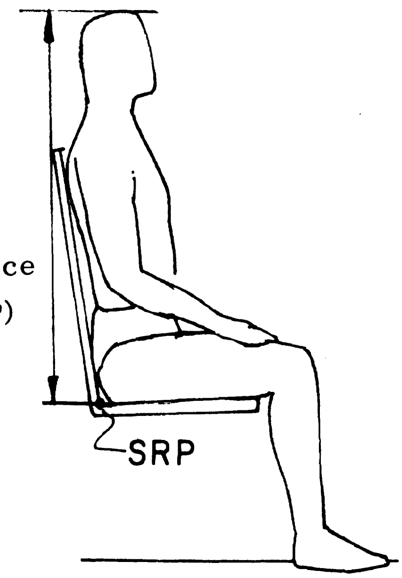
51. Subscapular Skinfold - Subject is in a standing, relaxed posture. The site is located on the subject below the inferior angle of the right scapula. The skinfold is lifted in a direction parallel to the ribs, with the skinfold angled upward medially and downward laterally at about 45° from the horizontal. A reading is made with the Lange Skinfold Caliper within 3 sec after application of the caliper, and the average is taken of several readings.



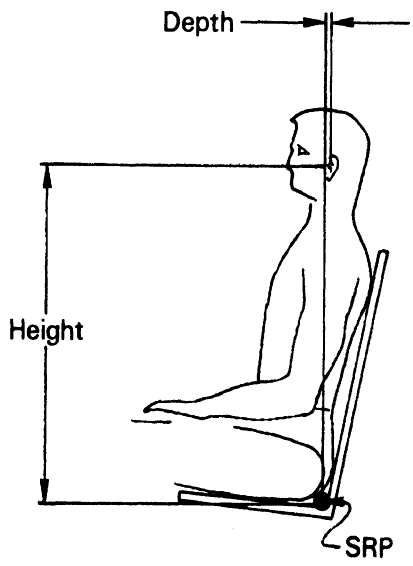
52. Suprailiac Skinfold - The subject stands in relaxed posture. The site is located superior to the lateral aspect of the iliac crest on the right side. The skinfold is lifted parallel to the pelvis and angled slightly upward posteriorly. A reading is made with the Lange Skinfold Caliper within 3 sec after application of the caliper, and the average is taken of several readings.



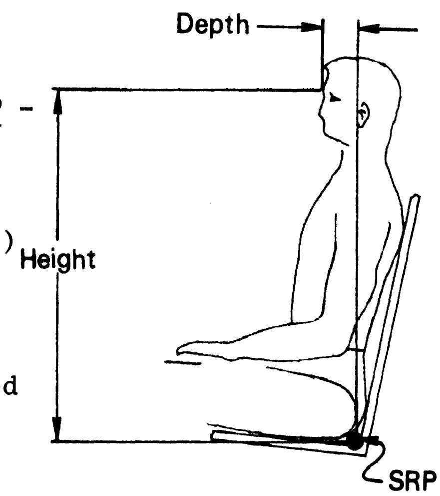
53. Normal Sitting Height - Subject sits in relaxed posture on the simulated auto seat, but with head in Frankfort Plane. The perpendicular distance from the floor to vertex is measured with the anthropometer, and the distance from the floor to the Seat Reference Point (SRP) is subtracted.



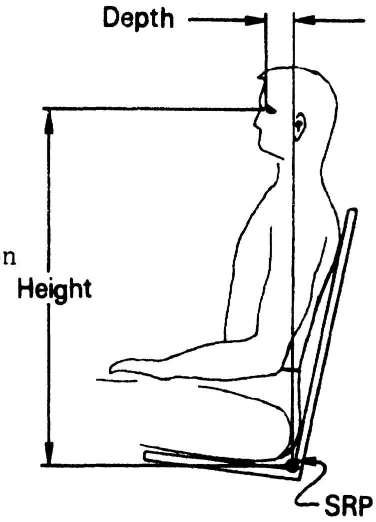
54, 55. Tragion Height and Depth from SRP - Subject is seated in relaxed posture, with head in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from the SRP to the left tragion are calculated from photographs. Dimensions superior and anterior to the SRP are defined as positive.



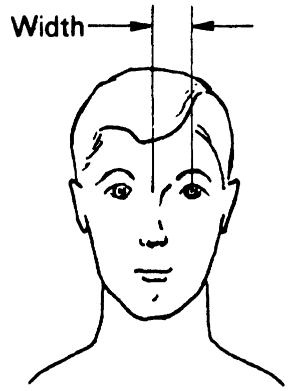
56, 57. Glabella Height and Depth from SRP - Subject is seated in relaxed posture, with head in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from the SRP to glabella are calculated from photographs. Dimensions superior and anterior to the SRP are defined as positive.



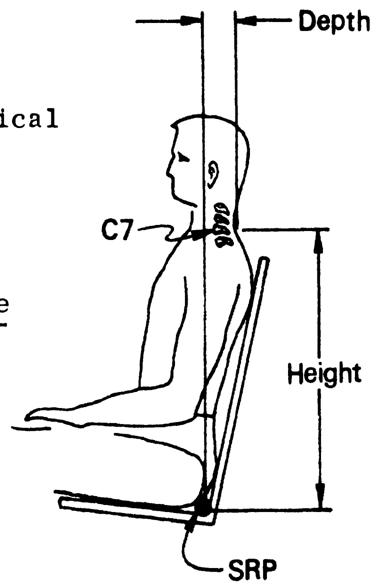
58, 59. Eye Ellipse Point Height and Depth from SRP - Subject is seated in relaxed posture with head in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from the SRP to the maximum protrusion of the surface of the eye (at the level of the pupil) are calculated from photographs. Dimensions superior and anterior to the SRP are defined as positive.



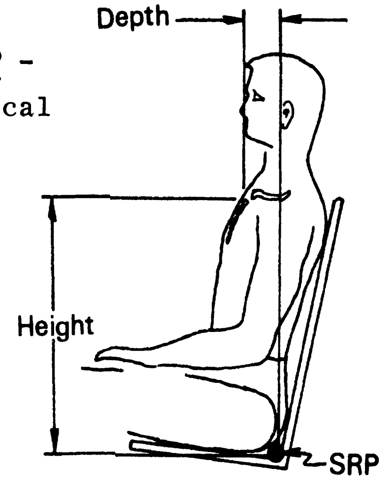
60. Eye Ellipse Point Width - The horizontal distance from the mid-sagittal plane of the body (as represented by the glabella landmark) to the pupil of the left eye is calculated from the Frankfort Plane neutral position photographs.



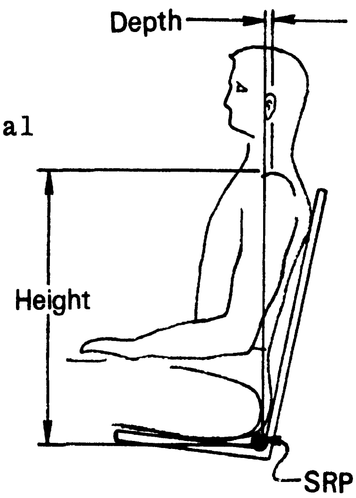
61, 62. Cervicale Height and Depth from SRP - Subject is seated in relaxed posture. The vertical (height) and horizontal (depth) distances from the SRP to the cervicale landmark (at the level of the spinous process of the seventh cervical vertebra) is calculated from the Frankfort Plane neutral position photographs. Dimensions superior and anterior to the SRP are defined as positive.



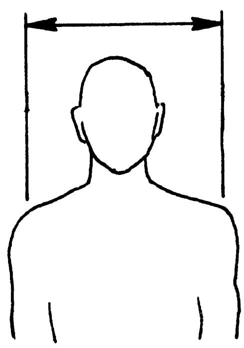
63, 64. Suprasternale Height and Depth from SRP - Subject is seated in relaxed posture. The vertical (height) and horizontal (depth) distances from the SRP to suprasternale, in the mid-sagittal plane of the body, are calculated from the Frankfort Plane neutral position photographs. Dimensions superior and anterior to the SRP are defined as positive.



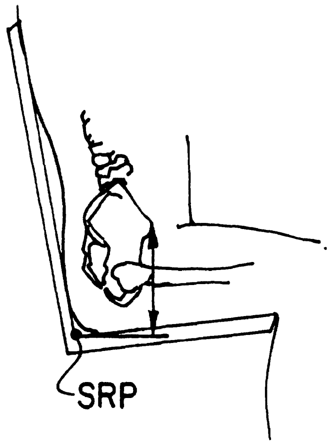
65, 66. Shoulder Height and Depth from SRP - Subject is seated in relaxed posture. The vertical (height) and horizontal (depth) distances from the SRP to a marker placed at the top of the shoulder (in the region of acromion) are calculated from the Frankfort Plane neutral position photographs. Dimensions superior and anterior to the SRP are defined as positive.



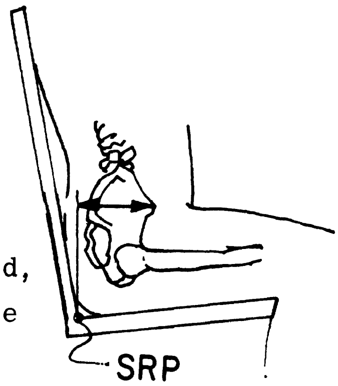
67. Shoulder Breadth - Subject is seated in relaxed posture. The horizontal distance between markers placed at the top of the right and left shoulders (in the region of acromion) is calculated from the Frankfort Plane neutral position photographs.



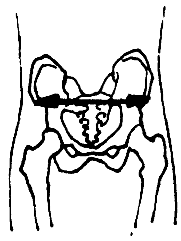
68. Anterior Superior Iliac Spine Height from SRP - Subject is seated in relaxed posture. The perpendicular distance from the floor to the right anterior superior iliac spine is measured with the anthropometer. The distance from the floor to SRP is subtracted, and the reported dimension is the height of the spine above the SRP.



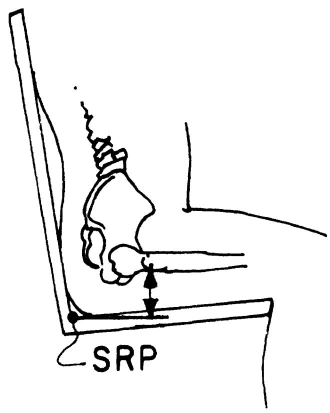
69. Anterior Superior Iliac Spine Depth from SRP - Subject is seated in relaxed posture. The horizontal distance from the wall to the right anterior superior iliac spine is measured with the anthropometer. The distance from the wall to the SRP is subtracted, and the reported dimension is the positive distance from the SRP to the spine.



70. Bispinous Breadth - The subject stands in relaxed posture, feet together, arms at the sides. Using the anthropometer, the horizontal distance is measured between the lateral margins of the anterior superior iliac spines.

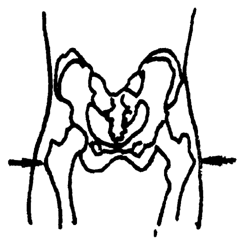


71. Trochanterion Height from SRP - The subject sits in relaxed posture, with the buttocks against the seat back. The vertical distance is measured, using the anthropometer, from the right side trochanterion mark (located while the subject is seated) to the floor. The distance from the floor to SRP is subtracted, and the reported dimension is trochanterion height above SRP.

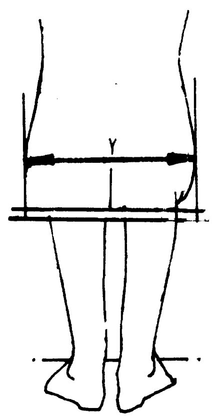


72. Trochanterion Depth from SRP - Subject is seated in relaxed posture with buttocks against seat back. Using the anthropometer, the horizontal distance is measured from the right side trochanterion mark (located while the subject is seated) to the wall. The distance from the wall to SRP is subtracted, and the reported depth is the positive distance from SRP to trochanterion.

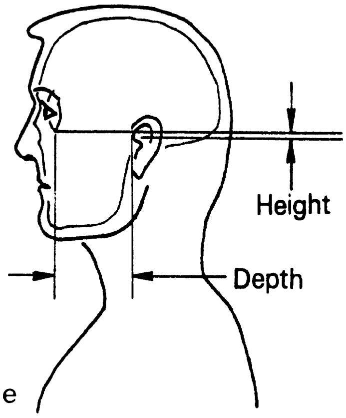
73. Bitrochanterion Diameter - The subject stands in relaxed posture, feet together, arms at the sides. Using the anthropometer, the horizontal distance is measured between the most lateral protuberances of the greater trochanters.



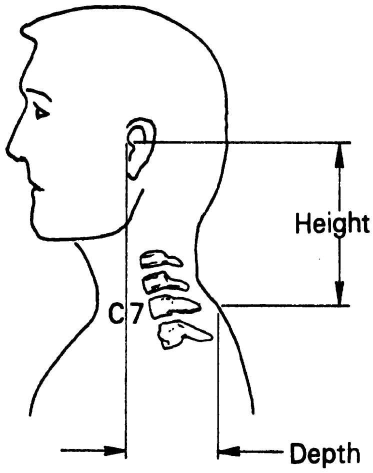
74. Hip Breadth (Seated) - Subject is seated in erect posture. The measurement is taken from the rear of the subject. The beam anthropometer is used to measure the maximum breadth of the hips at the level of the greater trochanters of the left and right femora. Light pressure is applied with the instrument.



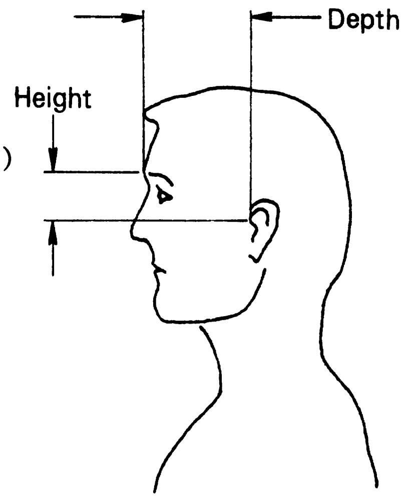
75, 76. Infraorbitale Height and Depth from Tragion - The subject's head is in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from the tragion to the most inferior point on the orbit of the eye are calculated from photographs. Since the head is in Frankfort Plane, infraorbitale height relative to tragion height should be approximately equal. Dimensions superior and anterior to tragion are defined as positive.



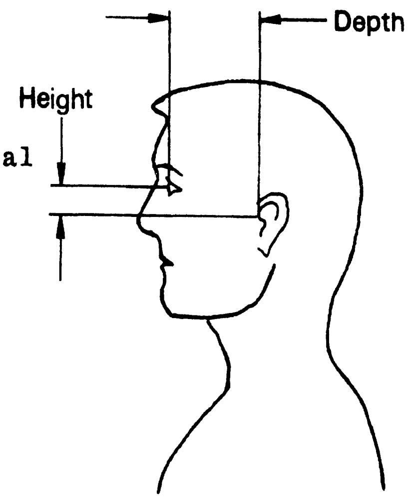
77, 78. Tragion Height and Depth from Cervicale - Subject is seated in relaxed posture, with head in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from cervicale to tragion are calculated from photographs. Dimensions superior and anterior to cervicale are defined as positive.



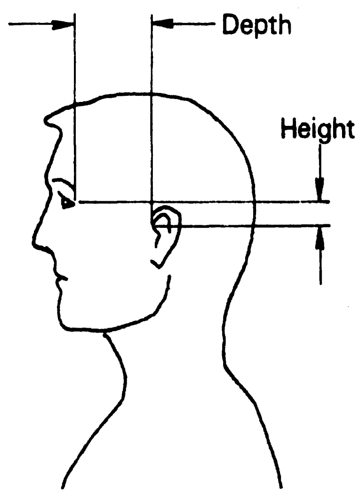
79, 80. Glabella Height and Depth from Tragion - The subject's head is in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from tragion to glabella are calculated from photographs. Dimensions superior and anterior to tragion are defined as positive.



81, 82. Eye Ellipse Point Height and Depth from Tragion - The subject's head is in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from tragion to the maximum protrusion of the eye (at the level of the pupil) are calculated from photographs. Dimensions superior and anterior to tragion are defined as positive.



83, 84. Ectocanthus Height and Depth from Tragion - The subject's head is in Frankfort Plane neutral position. The vertical (height) and horizontal (depth) distances from tragion to the lateral intersection of the upper and lower eyelids (ectocanthus) are calculated from photographs. Dimensions superior and anterior to tragion are defined as positive.



VII. Glossary of Anatomical Landmarks

Acromion - the superior lateral margin on the acromion process of the scapula.

Axilla - the armpit.

Cervicale - the dorsal tip of the spinous process of the seventh cervical vertebra.

Chin-neck intersect - the most posterior projection of the chin upon the neck when viewed from the side.

Clavicale - the most medio-superior projection of the clavicle at the sterno-clavicular joint.

Ectocanthus - the point at the lateral margin of the eye where the upper and lower eyelids intersect.

Fibulare - the most superior lateral projection of the head of the fibula.

Frankfort Plane - the head is oriented such that tragion and the lowest point on the bony orbit of the eye form a horizontal plane parallel to the floor surface.

Glabella - the most anterior point on the brow ridge in the mid-sagittal plane.

Gluteal Furrow - the posterior furrow in the standing position at the junction of the buttock and thigh.

Infraorbitale - the lowest point on the inferior margin of the bony eye orbit.

Lateral Malleolus - the most lateral bony projection of the ankle.

Menton - the point at the tip of the chin in the mid-sagittal plane.

Navicular - a wrist bone at the base of the hand whose proximal margin is found approximately at the distal wrist crease.

Occipital - the posterior bone of the skull.

Olecranon process - the proximal tip of the ulnar bone.

Omphalion - the umbilicus.

Opisthocranion - the most posterior bony projection at the back of the skull in the mid-sagittal plane.

Patella - the knee cap.

Radiale - the most superior lateral projection of the head of the radius found superficially at the level of the elbow dimple.

Stylion - the most distal tip of the radial styloid process.

Suprasternale - the lowest point on the superior margin of the sternum.

Tragion - the anterior limit of the cartilaginous notch located superior to the tragus of the left ear.

Trochanterion - the most lateral point palpable on the greater trochanter of the femur.

Vertex - the highest point on the head in the mid-sagittal plane when the head is aligned in the Frankfort Plane.

APPENDIX B

ANTHROPOMETRY-DESCRIPTIVE STATISTICS

Summary descriptive statistics from the anthropometry portion of the study are contained in this appendix. These data are reported in the following order:

Table	
B.1	All Subjects Combined
B.2	Subjects Grouped by Sex--Females
B.3	--Males
B.4	Subjects Grouped by Sex and Age--Females, 18-24 yrs
B.5	--Females, 35-44 yrs
B.6	--Females, 62-74 yrs
B.7	--Males, 18-24 yrs
B.8	--Males, 35-44 yrs
B.9	--Males, 62-74 yrs

The data tables are in the format produced by the University of Michigan Statistical Research Laboratory Michigan Interactive Data Analysis System (MIDAS). Each of the measurements is given a code name; the measurement name associated with the code names are identified below. All dimensions are in centimeters unless otherwise noted.

CODE NAME	MEASUREMENT NAME	MEAS. NO. (see App. A)
WT(KG)	Weight in kg	2.2x1
WT(LB)	Weight in lb	1
STAT(CM)	Stature	2
PONDINDX	Ponderal Index	$Ht/\sqrt[3]{wt}$
ERSITHT	Erect Sitting Height	3
HEADCIR	Head Circumference	4
HEADELPS	Bennett Ellipse Circumference	5
BITRGDI	Bitragion Diameter	6
HEADBR	Head Breadth	7
HEADLG	Head Length	8
SAGARC	Sagittal Arc Length	9
CORARC	Coronal Arc Length	10

CODE NAME	MEASUREMENT NAME	MEAS. NO. (see App. A)
BITRGGLB	Bitragion-Glabella Arc Length	11
BITRGMEN	Bitragion-Menton Arc Length	12
BITRGINA	Bitragion-Inion Arc Length	13
FACEHT	Facial Height	14
LATNKBR	Lateral Neck Breadth	15
APNKBR	Anterior-Posterior Neck Breadth	16
SUPNKCIR	Superior Neck Circumference	17
INFNKCIR	Inferior Neck Circumference	18
POSTNKLG	Posterior Neck Length	19
BIACRBR	Biacromial Breadth	20
BIDELTBR	Shoulder Breadth (Bideltoid)	21
CHESTHT	Chest Height	22
CHESTBR	Chest Breadth	23
CHESTCIR	Chest Circumference	24
WAISTHT	Waist Height	25
WAISTBR	Waist Breadth	26
WAISTCIR	Waist Circumference	27
HIPHT	Hip Height	28
HIPBRSTD	Hip Breadth (Standing Erect)	29
HIPCIR	Hip Circumference	30
ACRRADLG	Acromion-Radiale Length	31
ARMCIRAX	Upper Arm Circ. (at Axilla)	32
ARMCIREL	Upper Arm Circ. (above Elbow)	33
BICFLCIR	Biceps Flexed Circumference	34
RADSTYLG	Radiale-Stylion Length	35
FRARMCIR	Forearm Circumference	36
WRISTCIR	Wrist Circumference	37
HANDLG	Hand Length	38
TRCFEMLG	Trochanter-Femoral Condyle Length	39
UPTHICIR	Upper Thigh Circumference	40
LWTHICIR	Lower Thigh Circumference	41
FIBULALG	Fibula Length	42
FIBULAHT	Fibula Height	43
CALFCIR	Calf Circumference	44
ANKLECIR	Ankle Circumference	45
FOOTLG	Foot Length	46
FOOTBR	Ball-of-Foot Breadth	47
HUMDIA	Humeral Biepicondylar Dia.	48
FEMDIA	Femoral Biepicondylar Dia.	49
TRICPSF	Triceps Skinfold (mm)	50
SUBSCPSF	Subscapular Skinfold (mm)	51
SUPILSF	Suprailiac Skinfold (mm)	52
NRMSITHT	Normal Sitting Height (re SRP)	53
TRAGHTS	Tragion Height (re SRP)	54
TRAGDPS	Tragion Depth (re SRP)	55
BITRGDI	Bitragion Diameter	6
GLABHTS	Glabella Height (re SRP)	56
GLABDPS	Glabella Depth (re SRP)	57
EYELPHTS	Eye Ellipse Point Height (re SRP)	58
EYELPDPS	Eye Ellipse Point Depth (re SRP)	59

CODE NAME	MEASUREMENT NAME	MEAS. NO. (see App. A)
EYELPWDG	Eye Ellipse Point Width (re Glabella)	60
C7HTS	Cervicale Height (re SRP)	61
C7DPS	Cervicale Depth (re SRP)	62
SSTRNHTS	Suprasternale Height (re SRP)	63
SSTRNDPS	Suprasternale Depth (re SRP)	64
SHLDRHTS	Shoulder Height (re SRP)	65
SHLDRDPS	Shoulder Depth (re SRP)	66
SHLDRBR	Shoulder Breadth	67
ILCSPHTS	Anterior Superior Iliac Spine Ht (re SRP)	68
ILCSPDPS	Anterior Superior Iliac Spine Depth (re SRP)	69
BISPNBR	Bispinous Breadth	70
TRCHHTS	Trochanter Height (re SRP)	71
TRCHDPS	Trochanter Depth (re SRP)	72
BITRCHDI	Bitrochanter Diameter	73
HIPBRSIT	Hip Breadth (Seated Erect)	74
ORBHTT	Infraorbitrale Height (re Tragion)	75
ORBDPT	Infraorbitrale Depth (re Trag.)	76
TRAGHTC7	Tragion Height (re Cervicale)	77
TRAGDPC7	Tragion Depth (re Cervicale)	78
GLABHTT	Glabella Height (re Tragion)	79
GLABDPT	Glabella Depth (re Trag.)	80
EYELPHTT	Eye Ellipse Point Ht (re Trag.)	81
EYELPDPT	Eye Ellipse Point Depth (re Trag.)	82
ECTCNATT	Ectocanthus Height (re Trag.)	83
ECTCNDPT	Ectocanthus Depth (re Trag.)	84

The remaining measurements are the X, Y and Z-direction distances from the Seat Reference Point to the eight landmarks obtained from the "Anthropometry Neutral Position" photographs. All dimensions are in centimeters, relative to Seat Reference Point.

CODE NAME	MEASUREMENT NAME		MEAS. NO. (see App. A)
SHLDRSX	Shoulder Point	-X Direction	66
SHLDRSY	Shoulder Point	-Y Direction	
SHLDRSZ	Shoulder Point	-Z Direction	65
C7 SX	Cervicale	-X Direction	62
C7 SY	Cervicale	-Y Direction	
C7 SZ	Cervicale	-Z Direction	61

CODE NAME	MEASUREMENT NAME		MEAS. NO. (see App. A)
SSTRNSX	Suprasternale	-X Direction	64
SSTRNSY	Suprasternale	-Y Direction	
SSTRNSZ	Suprasternale	-Z Direction	63
TRAG SX	Tragion	-X Direction	55
TRAG SY	Tragion	-Y Direction	
TRAG SZ	Tragion	-Z Direction	54
ORBITSX	Infraorbitale	-X Direction	
ORBITSY	Infraorbitale	-Y Direction	
ORBITSZ	Infraorbitale	-Z Direction	
GLAB SX	Glabella	-X Direction	57
GLAB SY	Glabella	-Y Direction	
GLAB SZ	Glabella	-Z Direction	56
EYELPSX	Eye Ellipse Point	-X Direction	59
EYELPSY	Eye Ellipse Point	-Y Direction	
EYELPSZ	Eye Ellipse Point	-Z Direction	58
ECCANSX	Ectocanthus	-X Direction	
ECCANSY	Ectocanthus	-Y Direction	
ECCANSZ	Ectocanthus	-Z Direction	

The following summary statistics are reported for each measurement:

Column Heading	Statistic
N	Number of Subjects in the Group
MEAN	Numerical Average
STD DEV	Standard Deviation
SE OF MEAN	Standard Error of Mean
MINIMUM	Smallest Observation
MAXIMUM	Largest Observation
COEFF VAR	Coefficient of Variation (Mean/Std Dev)
5TH %ILE	Fifth Percentile (Calculated)
50TH %ILE	Fiftieth Percentile (Calculated)
95TH %ILE	Ninety-fifth Percentile (Calculated)

Note: MIDAS specifies, as the percentile, the individual measurement which is closest to the requested percentile. For example, in a dataset of 96 observations, the 5th smallest is called the 5th percentile, the 48th in rank is the 50th percentile and the 91st is the 95th percentile. This approach can cause misleading errors when small subsets of the data are analyzed (ex.: for a group of 15 subjects, the minimum value is also called the 5th percentile). Therefore, the percentiles are not included in Tables B.4 through B.9.

Table B.1 ANTHROPOMETRY-ALL SUBJECTS COMBINED

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR	5TH %ILE	50TH %ILE	95TH %ILE
WT(KG)	96	67.147	11.887	1.2133	42.500	103.64	.177	49.545	65.455	88.409
WT(LB)	96	147.72	26.152	2.6692	93.500	228.00	.177	109.000	144.000	194.500
STAT(CM)	96	166.26	8.8356	.90178	145.50	186.40	.053	151.700	166.200	183.100
PONDINDX	96	41.118	2.1352	.21792	34.783	45.510	.052	37.560	41.409	44.273
ERSITHT	96	87.309	4.2664	.43544	76.600	97.300	.049	79.600	87.500	94.700
HEADCIR	96	56.998	2.0470	.20892	52.600	62.300	.036	53.800	57.000	60.500
HEADELPS	96	65.783	2.5106	.25624	60.400	71.800	.038	62.100	65.700	70.000
BITRGDI	96	13.571	.68532	.69945 -1	12.100	15.400	.050	12.500	13.600	14.900
HEADBR	96	15.075	.62492	.63781 -1	13.800	16.700	.041	14.100	15.000	16.200
HEADLG	96	18.569	.85856	.87626 -1	16.800	20.900	.046	17.100	18.600	20.100
SAGARC	96	35.305	1.5281	.15596	32.300	40.100	.043	32.600	35.200	38.200
CORARC	96	34.590	1.5619	.15941	31.200	38.000	.045	32.000	34.400	37.500
BITRGGLB	96	29.318	1.2882	.13147	26.700	33.200	.044	27.200	29.200	31.400
BITRGMEN	95	31.258	1.7395	.17847	28.000	35.500	.056	28.600	31.200	34.000
BITRGINA	96	26.927	1.3949	.14237	24.000	32.000	.052	24.800	26.900	28.900
FACEHT	96	12.912	.79037	.80667 -1	11.200	15.000	.061	11.600	12.900	14.300
LATNKBR	96	10.077	1.0502	.10718	8.4000	13.200	.104	8.600	9.800	12.300
APNKBR	96	10.358	1.1890	.12135	8.1000	13.700	.115	8.600	10.300	12.600
SUPNKCIR	96	36.755	4.1931	.42795	30.400	46.900	.114	30.600	36.200	43.800
INFNKCIR	95	38.608	3.2032	.32865	31.300	45.900	.083	33.500	39.100	44.200
POSTNKLG	96	15.954	1.7347	.17704	11.500	20.000	.109	13.200	16.000	18.700
BIACRBR	95	36.639	2.9129	.29886	30.400	44.200	.080	32.300	36.100	41.600
BIDELTBR	96	43.473	3.7127	.37892	35.800	52.700	.085	38.600	43.300	49.500
CHESTHT	93	125.48	6.7174	.69656	107.50	140.80	.054	113.700	125.100	136.100
CHESTBR	93	29.552	3.1478	.32641	23.300	38.400	.107	24.400	29.600	34.400
CHESTCIR	93	91.774	7.9325	.82256	75.800	108.10	.086	80.300	90.800	104.400
WAISTHT	93	102.20	5.3383	.55356	89.000	118.80	.052	94.400	101.300	111.500
WAISTBR	93	27.317	3.4300	.35567	20.700	36.900	.126	21.700	27.200	33.000
WAISTCIR	94	79.684	10.919	1.1262	60.900	108.50	.137	63.500	79.300	99.000
HIPHT	91	87.214	5.1614	.54106	72.700	98.800	.059	78.900	87.300	95.800
HIPBRSTD	92	34.041	2.3685	.24693	29.100	43.000	.070	30.800	33.700	38.200
HIPCIR	95	98.411	7.7660	.79677	81.800	127.80	.079	88.200	97.900	111.300
ACRRADLG	96	31.436	2.1865	.22316	26.900	37.700	.070	28.300	31.000	35.700
ARMCIRAX	96	30.843	3.2095	.32757	23.800	39.100	.104	25.800	31.200	36.000
ARMCIREL	96	24.658	2.4438	.24942	19.300	32.400	.099	21.100	24.500	28.700
BICFLCIR	96	30.326	3.5633	.36367	23.300	39.300	.117	24.700	30.100	36.400
RADSTYLG	96	23.932	1.8409	.18788	19.200	28.200	.077	21.200	23.600	27.000
FRARMCIR	96	25.244	2.5381	.25904	20.000	31.400	.101	21.500	25.000	29.600
WRISTCIR	96	16.390	1.5349	.15665	13.500	20.200	.094	14.400	16.300	19.600
HANDLG	96	17.879	1.1141	.11371	15.800	21.600	.062	16.200	17.800	19.700
TRCFEMLG	93	42.441	2.4805	.25721	36.300	48.500	.058	38.300	42.600	46.700
UPTHICIR	95	57.529	5.7310	.58798	46.300	77.700	.100	48.400	56.700	67.500
LWTHICIR	96	38.534	3.2719	.33394	30.700	50.100	.085	33.600	38.600	44.500
FIBULALG	96	42.234	2.9929	.30546	35.000	50.100	.071	36.300	42.200	47.400
FIBULAHT	96	47.870	3.3863	.34562	40.100	56.500	.071	41.900	47.500	53.900
CALFCIR	96	35.473	2.6191	.26731	29.200	43.500	.074	31.000	35.500	40.000
ANKLECIR	96	21.494	1.4068	.14358	18.200	25.200	.065	18.700	21.500	24.400
FOOTLG	93	24.761	1.7879	.18539	20.200	29.600	.072	22.400	24.600	28.100
FOOTBR	93	9.0398	.72609	.75292 -1	7.4000	11.000	.080	7.900	9.000	10.300
HUMDIA	96	6.5594	.70181	.71629 -1	5.3000	8.9000	.107	5.600	6.500	7.800
FEMDIA	95	8.9589	.71734	.73597 -1	7.4000	10.700	.080	7.900	9.000	10.400
TRICPSF	96	13.146	7.1027	.72492	3.9000	33.700	.540	4.800	12.000	30.400
SUBSCPSF	96	15.593	8.3036	.84748	4.4000	44.200	.533	6.200	13.100	31.800
SUPILSF	96	12.373	6.7141	.68526	2.6000	32.600	.543	3.800	10.800	25.700

NRMSITHT	96	84.796	4.2503	.43379	73.300	96.300	.050	77.800	84.800	91.300
TRAGHTS	92	71.882	4.0240	.41954	62.200	82.400	.056	64.600	71.700	78.300
TRAGDPS	92	-.84022	2.9577	.30836	-9.7000	6.0000	-3.520	-4.900	-.800	4.600
BITRGDI	96	13.571	.68532	.69945 -1	12.100	15.400	.050	12.500	13.600	14.900
GLABHTS	95	75.797	3.9681	.40712	66.000	85.900	.052	68.700	75.400	82.900
GLABDPS	95	8.9316	2.8788	.29536	2.5000	15.700	.322	4.200	8.800	14.500
EYELPHTS	95	74.059	3.9461	.40486	64.700	84.400	.053	67.400	73.900	80.800
EYELPDPS	95	7.4958	2.8592	.29335	.80000	14.400	.381	2.600	7.200	13.000
EYELPWDG	95	3.1537	.26329	.27013 -1	2.7000	3.8000	.083	2.700	3.100	3.700
C7HTS	95	60.877	3.4863	.35769	52.600	69.900	.057	55.500	60.400	66.800
C7DPS	95	-9.5000	2.4727	.25369	-17.300	-2.5000	-.260	-12.700	-9.900	-4.800
SSTRNHTS	91	54.403	3.2101	.33651	46.600	61.700	.059	49.100	54.200	59.400
SSTRNDPS	91	3.2912	2.5060	.26270	-1.9000	10.100	.761	-1.500	3.200	7.700
SHLDRHTS	96	54.616	3.4831	.35549	45.800	62.700	.064	48.900	54.400	60.500
SHLDRDPS	96	-4.2625	2.7100	.27658	-8.8000	2.6000	-.636	-8.300	-4.600	.600
SHLDRBR	96	37.987	3.1570	.32221	33.000	47.500	.083	33.200	37.700	44.200
ILCSPHTS	95	19.729	1.7987	.18454	16.300	28.200	.091	17.600	19.400	22.200
ILCSPDPS	94	11.956	1.8074	.18642	7.7000	17.800	.151	9.100	12.100	15.000
BISPNBR	95	23.388	2.0185	.20710	18.500	29.800	.086	20.200	23.400	27.000
TRCHHTS	92	8.8674	1.4365	.14977	6.6000	14.000	.162	7.000	8.600	11.600
TRCHDPS	91	10.368	1.7931	.18796	6.1000	16.200	.173	7.700	10.100	13.400
BITRCHDI	95	31.502	2.1864	.22432	27.400	38.700	.069	28.500	31.100	35.400
HIPBRSIT	95	37.988	3.8760	.39767	28.700	49.800	.102	31.700	37.900	46.100
ORBHTT	92	.30652	.58831	.61336 -1	-1.2000	1.9000	1.919	-.700	.300	1.400
ORBDPT	92	8.2293	1.2754	.13297	5.9000	11.700	.155	6.800	7.800	10.800
TRAGHTC7	91	11.034	1.3223	.13862	7.9000	13.500	.120	8.500	11.100	13.100
TRAGDPC7	91	8.6780	1.7720	.18576	4.4000	13.100	.204	5.800	8.600	11.500
GLABHTT	92	4.0283	.71473	.74516 -1	2.5000	6.1000	.177	3.000	4.000	5.100
GLABDPT	92	9.7674	1.3882	.14473	7.3000	13.500	.142	7.900	9.400	12.600
EYELPHTT	92	2.2783	.53572	.55853 -1	.80000	3.8000	.235	1.400	2.300	3.000
EYELPDPT	92	8.3228	1.2605	.13141	6.1000	11.800	.151	6.900	8.000	10.900
ECTCNATT	92	2.1891	.53256	.55523 -1	.70000	3.6000	.243	1.200	2.200	2.900
ECTCNDPT	92	7.3446	1.2437	.12967	5.2000	10.500	.169	5.900	7.000	9.800
SHLDRSX	96	-4.2625	2.7100	.27658	-8.8000	2.6000	-.636	-8.300	-4.600	.600
SHLDRSY	96	16.578	2.3069	.23545	11.300	22.100	.139	12.800	16.500	20.200
SHLDRSZ	96	54.616	3.4831	.35549	45.800	62.700	.064	48.900	54.400	60.500
C7 SX	95	-9.5000	2.4727	.25369	-17.300	-2.5000	-.260	-12.700	-9.900	-4.800
C7 SY	96	-2.0115	1.4088	.14379	-5.9000	1.3000	-.700	-4.600	-2.000	-.100
C7 SZ	95	60.877	3.4863	.35769	52.600	69.900	.057	55.500	60.400	66.800
SSTRNSX	91	3.2912	2.5060	.26270	-1.9000	10.100	.761	-1.500	3.200	7.700
SSTRNSY	95	-1.9411	1.3688	.14043	-5.7000	1.3000	-.705	-4.500	-1.900	-.100
SSTRNSZ	91	54.403	3.2101	.33651	46.600	61.700	.059	49.100	54.200	59.400
TRAG SX	92	-.77500	2.8232	.29434	-6.9000	6.0000	-3.643	-4.900	-.800	4.600
TRAG SY	83	5.9880	1.6510	.18122	2.4000	9.6000	.276	3.300	6.100	9.000
TRAG SZ	92	71.882	4.0240	.41954	62.200	82.400	.056	64.600	71.700	78.300
ORBITSX	95	7.4000	2.8215	.28948	.90000	14.300	.381	2.400	7.200	12.800
ORBITSY	95	1.0232	1.5869	.16281	-3.1000	5.2000	1.551	-1.600	1.100	3.300
ORBITSZ	95	72.094	3.8382	.39379	62.900	82.100	.053	65.800	72.000	78.700
GLAB SX	95	8.9316	2.8788	.29536	2.5000	15.700	.322	4.200	8.800	14.500
GLAB SY	95	-2.2611	1.5593	.15999	-6.3000	1.8000	-.690	-4.900	-2.300	.200
GLAB SZ	95	75.797	3.9681	.40712	66.000	85.900	.052	68.700	75.400	82.900
EYELPSX	95	7.4958	2.8592	.29335	.80000	14.400	.381	2.600	7.200	13.000
EYELPSY	95	.90000	1.5310	.15707	-3.2000	4.6000	1.701	-1.400	1.000	3.400
EYELPSZ	95	74.059	3.9461	.40486	64.700	84.400	.053	67.400	73.900	80.800
ECCANSX	95	6.5105	2.8506	.29246	0.	13.200	.438	1.800	6.300	11.800
ECCANSY	95	2.2737	1.5651	.16058	-1.9000	6.2000	.688	0.	2.400	4.700
ECCANSZ	95	73.971	3.9440	.40465	64.700	84.400	.053	67.300	73.800	80.700

Table B.2

ANTHROPOMETRY-BY SEX-FEMALES

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR	5TH %ILE	50TH %ILE	95TH %ILE
WT(KG)	48	60.846	10.311	1.4883	42.500	94.091	.169	48.636	58.636	83.636
WT(LB)	48	133.86	22.684	3.2742	93.500	207.00	.169	107.000	129.000	184.000
STAT(CM)	48	159.68	5.7054	.82351	145.50	173.70	.036	149.000	159.600	167.900
PONDINDX	48	40.824	2.4152	.34860	34.783	45.510	.059	36.249	40.879	44.086
ERSITHT	48	84.567	3.3006	.47641	76.600	91.100	.039	77.900	84.500	89.300
HEADCIR	48	55.700	1.6013	.23113	52.600	59.100	.029	53.500	55.600	58.200
HEADELPS	48	64.202	1.8705	.26999	60.400	68.800	.029	61.000	64.100	67.400
BITRGDI	48	13.225	.53256	.76868 -1	12.100	14.300	.040	12.200	13.100	14.200
HEADBR	48	14.783	.48480	.69576 -1	13.800	15.800	.033	13.900	14.800	15.600
HEADLG	48	18.027	.60415	.87201 -1	16.800	19.200	.034	17.100	18.000	18.900
SAGARC	48	34.712	1.4345	.20705	32.300	40.100	.041	32.400	34.500	36.600
CORARC	48	33.946	1.3714	.19795	31.200	38.000	.040	32.000	34.000	36.800
BITRGGLB	48	28.577	.90324	.13037	26.700	31.000	.032	27.000	28.600	30.000
BITRGMEN	47	30.045	1.1342	.16544	28.000	32.200	.038	28.500	30.000	32.000
BITRGINA	48	26.217	1.1675	.16852	24.000	29.000	.045	24.400	26.200	28.500
FACEHT	48	12.437	.54329	.78417 -1	11.200	13.400	.044	11.600	12.600	13.300
LATNKBR	48	9.3750	.64791	.93518 -1	8.4000	11.200	.069	8.500	9.300	10.700
APNKBR	48	9.5750	.89668	.12943	8.1000	12.800	.094	8.300	9.400	10.900
SUPNKCIR	48	33.940	2.9947	.43224	30.400	43.200	.088	30.500	33.300	40.000
INFNKCIR	48	36.529	2.4453	.35295	31.300	42.200	.067	32.800	36.300	40.800
POSTNKLG	48	15.573	1.8069	.26081	11.500	18.800	.116	12.200	16.000	18.700
BIACRBR	48	34.746	1.7107	.24691	30.400	38.400	.049	31.900	34.800	37.800
BIDELTBR	48	41.277	2.8201	.40704	35.800	49.300	.068	38.400	40.500	47.500
CHESTHT	46	120.76	4.9052	.72323	107.50	131.10	.041	113.100	122.200	127.200
CHESTBR	46	27.526	2.5197	.37152	23.300	33.700	.092	23.900	27.100	32.300
CHESTCIR	47	86.504	6.1892	.90279	75.800	104.20	.072	77.800	84.800	99.100
WAISTHT	46	99.811	4.3209	.63708	89.000	110.40	.043	91.800	99.500	106.700
WAISTBR	46	25.202	2.6313	.38796	21.000	33.000	.104	21.500	24.600	29.900
WAISTCIR	47	73.457	9.3705	1.3668	60.900	99.300	.128	61.400	71.000	90.000
HIPHT	45	83.778	4.0276	.60039	72.700	91.800	.048	78.600	84.500	88.700
HIPBRSTD	45	34.060	2.9324	.43713	29.100	43.000	.086	30.700	33.600	40.100
HIPCIR	47	98.830	9.4255	1.3749	81.800	127.80	.095	87.600	97.500	121.700
ACRRADLG	48	29.904	1.2211	.17625	26.900	32.000	.041	27.800	29.900	31.800
ARMCIRAX	48	29.452	3.2168	.46431	23.800	38.600	.109	25.000	29.000	36.000
ARMCIREL	48	23.756	2.6316	.37984	19.300	32.400	.111	20.500	23.100	30.100
BICFLCIR	48	28.704	3.5641	.51443	23.300	39.300	.124	23.900	28.300	36.400
RADSTYLG	48	22.558	1.1463	.16545	19.200	25.500	.051	21.000	22.500	24.400
FRARMCIR	48	23.519	1.7818	.25718	20.000	28.000	.076	20.900	23.100	26.400
WRISTCIR	48	15.554	1.3290	.19183	13.500	20.200	.085	14.000	15.300	18.000
HANDLG	48	17.077	.66788	.96400 -1	15.800	19.100	.039	16.000	17.100	18.200
TRCFEMLG	45	41.907	2.3610	.35196	36.900	46.600	.056	38.300	42.000	45.500
UPTHICIR	47	58.900	5.9315	.86519	46.800	77.700	.101	51.200	57.400	69.400
LWTHICIR	48	38.371	3.7292	.53826	30.700	50.100	.097	33.600	38.200	44.600
FIBULALG	48	40.121	2.0932	.30213	35.000	44.300	.052	35.900	40.300	42.800
FIBULAHT	48	45.383	2.2680	.32736	40.100	49.700	.050	40.400	45.900	48.100
CALFCIR	48	34.829	2.7398	.39545	29.200	42.200	.079	30.600	34.600	39.400
ANKLECIR	48	20.773	1.2450	.17970	18.200	23.300	.060	18.300	21.000	22.300
FOOTLG	46	23.409	.97908	.14436	20.200	25.200	.042	22.100	23.400	25.200
FOOTBR	46	8.5652	.54496	.80351 -1	7.4000	9.7000	.064	7.800	8.500	9.600
HUMDIA	48	6.0604	.36771	.53074 -1	5.3000	7.3000	.061	5.400	6.100	6.500
FEMDIA	47	8.5277	.51529	.75163 -1	7.4000	9.9000	.060	7.800	8.500	9.400
TRICPSF	48	17.250	7.1736	1.0354	6.8000	33.700	.416	7.000	15.400	32.000
SUBSCPSF	48	17.077	9.5657	1.3807	4.4000	44.200	.560	7.300	13.400	37.400
SUPILSF	48	13.406	6.9008	.99605	2.6000	31.000	.515	4.200	11.000	25.700
NRMSITHT	48	82.069	3.3026	.47669	73.300	88.100	.040	76.800	82.000	87.200
TRAGHTS	45	69.411	3.2248	.48073	62.200	76.400	.046	63.700	69.400	74.600

TRAGDPS	45	-1.4356	2.7291	.40683		-6.9000	4.6000	-1.901	-5.500	-1.400	3.000
BITRGDI	48	13.225	.53256	.76868	-1	12.100	14.300	.040	12.200	13.100	14.200
GLABHTS	47	73.291	3.0524	.44523		66.000	79.400	.042	68.400	73.300	78.100
GLABDPS	47	7.9468	2.7322	.39854		2.5000	14.100	.344	3.500	8.000	12.800
EYELPHTS	47	71.613	3.0624	.44670		64.700	77.600	.043	66.400	71.400	76.500
EYELPDPS	47	6.6340	2.7065	.39478		1.2000	12.700	.408	2.200	6.700	11.200
EYELPWOG	47	3.0723	.26515	.38676	-1	2.7000	3.8000	.086	2.700	3.000	3.600
C7HTS	47	58.660	2.4802	.36178		52.600	63.700	.042	55.300	58.400	63.400
C7DPS	47	-9.5553	2.1993	.32080		-14.400	-4.6000	-.230	-12.500	-9.800	-5.000
SSTRNHTS	44	52.534	2.4132	.36381		46.600	57.800	.046	48.600	52.600	56.600
SSTRNDPS	44	2.7159	2.4343	.36699		-1.9000	7.3000	.896	-1.500	2.300	6.500
SHLDRHTS	48	52.512	2.4789	.35780		45.800	58.700	.047	48.800	52.600	56.300
SHLDRDPS	48	-4.0979	2.5982	.37501		-8.8000	2.0000	-.634	-7.800	-4.600	.400
SHLDRBR	48	35.750	1.9037	.27478		33.000	40.300	.053	33.100	35.600	39.200
ILCSPHTS	47	19.166	1.1189	.16320		16.300	21.300	.058	17.600	19.300	20.900
ILCSPDPS	46	12.539	1.9663	.28992		8.6000	17.800	.157	10.300	12.400	16.700
BISPNBR	48	23.058	1.8345	.26479		18.500	27.200	.080	20.200	22.900	25.900
TRCHHTS	44	8.6182	1.3577	.20468		6.6000	12.900	.158	6.800	8.400	10.500
TRCHDPS	43	10.100	1.7487	.25668		6.1000	14.400	.173	7.400	10.000	12.900
BITRCHDI	47	31.089	2.1035	.30683		27.400	38.700	.068	28.200	31.000	34.300
HIPBRSIT	47	39.304	3.8204	.55727		31.700	49.800	.097	34.300	39.000	46.100
ORBHTT	45	.44222	.55779	.83151	-1	-.80000	1.9000	1.261	-.300	.400	1.400
ORBDPT	45	7.9222	1.0869	.16202		5.9000	11.600	.137	6.600	7.700	10.300
TRAGHTC7	44	10.959	1.3837	.20860		7.9000	13.500	.126	8.500	11.000	12.800
TRAGDPC7	44	8.1750	1.5670	.23623		4.4000	12.300	.192	5.100	8.200	10.300
GLABHTT	45	3.9511	.65249	.97267	-1	2.5000	6.1000	.165	3.000	3.900	4.700
GLABDPT	45	9.2822	1.1454	.17075		7.3000	13.200	.123	7.700	9.200	11.400
EYELPHTT	45	2.2578	.47458	.70746	-1	.80000	3.2000	.210	1.600	2.300	2.900
EYELPDPT	45	7.9578	1.0446	.15572		6.1000	11.200	.131	6.800	7.700	10.100
ECTCNATT	45	2.1756	.48249	.71926	-1	.80000	3.1000	.222	1.200	2.200	2.800
ECTCNDPT	45	6.9956	1.0664	.15897		5.2000	10.400	.152	5.700	6.800	9.100
SHLDRSX	48	-4.0979	2.5982	.37501		-8.8000	2.0000	-.634	-7.800	-4.600	.400
SHLDRSY	48	15.515	1.9968	.28821		11.300	19.700	.129	12.600	15.600	18.400
SHLDRSZ	48	52.512	2.4789	.35780		45.800	58.700	.047	48.800	52.600	56.300
C7 SX	47	-9.5553	2.1993	.32080		-14.400	-4.6000	-.230	-12.500	-9.800	-5.000
C7 SY	48	-2.0104	1.5056	.21732		-5.0000	1.3000	-.749	-4.600	-2.100	.300
C7 SZ	47	58.660	2.4802	.36178		52.600	63.700	.042	55.300	58.400	63.400
SSTRNSX	44	2.7159	2.4343	.36699		-1.9000	7.3000	.896	-1.500	2.300	6.500
SSTRNSY	47	-1.9340	1.4703	.21447		-4.8000	1.3000	-.760	-4.500	-2.000	.300
SSTRNSZ	44	52.534	2.4132	.36381		46.600	57.800	.046	48.600	52.600	56.600
TRAG SX	45	-1.4356	2.7291	.40683		-6.9000	4.6000	-1.901	-5.500	-1.400	3.000
TRAG SY	42	5.7524	1.7636	.27213		2.4000	9.5000	.307	3.200	5.700	9.000
TRAG SZ	45	69.411	3.2248	.48073		62.200	76.400	.046	63.700	69.400	74.600
ORBITSX	47	6.5979	2.6849	.39163		1.0000	12.500	.407	2.100	6.800	11.200
ORBITSY	47	.94255	1.6720	.24388		-2.5000	5.2000	1.774	-1.400	1.000	3.700
ORBITSZ	47	69.802	2.9669	.43276		62.900	75.600	.043	64.500	69.800	74.400
GLAB SX	47	7.9468	2.7322	.39854		2.5000	14.100	.344	3.500	8.000	12.800
GLAB SY	47	-2.2468	1.6749	.24430		-6.1000	1.8000	-.745	-5.000	-2.100	.400
GLAB SZ	47	73.291	3.0524	.44523		66.000	79.400	.042	68.400	73.300	78.100
EYELPSX	47	6.6340	2.7065	.39478		1.2000	12.700	.408	2.200	6.700	11.200
EYELPSY	47	.83404	1.6250	.23703		-2.8000	4.6000	1.948	-1.400	1.000	3.500
EYELPSZ	47	71.613	3.0624	.44670		64.700	77.600	.043	66.400	71.400	76.500
ECCANSX	47	5.6723	2.7365	.39916		.10000	11.800	.482	1.000	5.800	10.300
ECCANSY	47	2.2128	1.6763	.24451		-1.7000	6.2000	.758	0.	2.400	5.000
ECCANSZ	47	71.538	3.0570	.44590		64.700	77.400	.043	66.300	71.300	76.400

Table B.3 ANTHROPOMETRY-BY SEX-MALES

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR	5TH %ILE	50TH %ILE	95TH %ILE
WT(KG)	48	73.449	9.9095	1.4303	54.318	103.64	.135	58.636	73.182	89.545
WT(LB)	48	161.59	21.801	3.1467	119.50	228.00	.135	129.000	161.000	197.000
STAT(CM)	48	172.84	6.0667	.87565	159.80	186.40	.035	164.800	172.100	185.100
PONDINDX	48	41.411	1.7903	.25841	37.898	45.290	.043	38.547	41.597	44.385
ERSITHT	48	90.052	3.2454	.46844	84.000	97.300	.036	84.700	89.200	95.700
HEADCIR	48	58.296	1.5699	.22660	54.700	62.300	.027	55.800	58.200	60.800
HEADELPS	48	67.365	2.0333	.29348	62.600	71.800	.030	63.800	67.300	70.700
BITRGDI	48	13.917	.64917	.93699 -1	12.500	15.400	.047	12.700	14.000	15.000
HEADBR	48	15.367	.61690	.89042 -1	14.100	16.700	.040	14.400	15.300	16.500
HEADLG	48	19.110	.72501	.10465	17.500	20.900	.038	18.100	19.000	20.300
SAGARC	48	35.898	1.3944	.20127	32.500	38.700	.039	33.600	35.800	38.300
CORARC	48	35.233	1.4844	.21426	31.500	38.000	.042	33.000	35.400	37.800
BITRGGLB	48	30.058	1.1907	.17186	27.300	33.200	.040	28.000	30.000	31.900
BITRGMEN	48	32.446	1.3710	.19788	29.100	35.500	.042	30.000	32.500	34.500
BITRGINA	48	27.637	1.2406	.17906	24.800	32.000	.045	25.700	27.800	29.100
FACEHT	48	13.387	.71179	.10274	12.000	15.000	.053	12.200	13.200	14.700
LATNKBR	48	10.779	.89584	.12930	9.3000	13.200	.083	9.400	10.700	12.300
APNKBR	48	11.142	.89439	.12909	9.5000	13.700	.080	9.900	11.100	12.900
SUPNKCIR	48	39.571	3.2213	.46496	34.300	46.900	.081	35.100	39.300	46.200
INFNKCIR	47	40.732	2.3957	.34946	32.000	45.900	.059	38.200	40.300	44.800
POSTNKLG	48	16.335	1.5875	.22914	13.500	20.000	.097	13.800	16.100	19.400
BIACRBR	47	38.572	2.6058	.38010	32.300	44.200	.068	34.600	38.800	43.000
BIDELTBR	48	45.669	3.1717	.45779	38.300	52.700	.069	40.200	45.600	49.800
CHESTHT	47	130.11	4.7486	.69266	120.50	140.80	.036	121.900	129.700	138.500
CHESTBR	47	31.534	2.3425	.34170	27.200	38.400	.074	28.700	31.200	35.700
CHESTCIR	46	97.159	5.5539	.81888	86.000	108.10	.057	87.900	97.300	105.800
WAISTHT	47	104.54	5.2351	.76362	93.200	118.80	.050	98.900	103.600	113.500
WAISTBR	47	29.387	2.8115	.41010	20.700	36.900	.096	25.600	29.200	34.000
WAISTCIR	47	85.911	8.6029	1.2549	67.700	108.50	.100	71.200	85.800	99.000
HIPHT	46	90.576	3.7493	.55280	82.000	98.800	.041	86.200	89.900	98.200
HIPBRSTD	47	34.023	1.6946	.24719	30.900	38.000	.050	31.300	33.700	36.800
HIPCIR	48	98.000	5.7726	.83320	86.500	111.30	.059	89.100	97.900	108.000
ACRRADLG	48	32.969	1.8375	.26521	29.400	37.700	.056	30.000	32.600	36.200
ARMCIRAX	48	32.233	2.5540	.36864	25.800	39.100	.079	28.500	32.400	36.000
ARMCIREL	48	25.560	1.8665	.26940	21.900	30.000	.073	22.600	25.500	28.600
BICFLCIR	48	31.948	2.7547	.39761	26.500	38.200	.086	27.500	32.000	35.700
RADSTYLG	48	25.306	1.2961	.18707	22.500	28.200	.051	23.100	25.200	27.400
FRARMCIR	48	26.969	1.9412	.28018	23.000	31.400	.072	23.700	27.300	31.000
WRISTCIR	48	17.225	1.2530	.18085	14.900	20.000	.073	15.400	17.000	19.600
HANDLG	48	18.681	.86533	.12490	17.000	21.600	.046	17.300	18.600	20.100
TRCFEMLG	48	42.942	2.5091	.36216	36.300	48.500	.058	38.800	42.600	47.000
UPTHICIR	48	56.187	5.2475	.75741	46.300	67.500	.093	48.400	55.200	64.500
LWTHICIR	48	38.698	2.7709	.39994	32.500	44.500	.072	34.300	39.000	43.700
FIBULALG	48	44.348	2.1448	.30957	40.200	50.100	.048	40.700	43.900	48.500
FIBULAHT	48	50.356	2.3252	.33561	46.500	56.500	.046	46.800	50.300	54.600
CALFCIR	48	36.117	2.3479	.33889	31.000	43.500	.065	32.400	36.300	40.000
ANKLECIR	48	22.215	1.1785	.17011	20.200	25.200	.053	20.800	22.000	24.800
FOOTLG	47	26.085	1.3547	.19760	23.800	29.600	.052	24.300	25.700	28.900
FOOTBR	47	9.5043	.56413	.82287 -1	8.5000	11.000	.059	8.700	9.400	10.300
HUMDIA	48	7.0583	.59316	.85616 -1	5.9000	8.9000	.084	6.300	6.900	8.400
FEMDIA	48	9.3812	.63335	.91416 -1	7.8000	10.700	.068	8.400	9.300	10.600
TRICPSF	48	9.0417	4.0132	.57925	3.9000	21.600	.444	4.400	7.800	17.000
SUBSCPSF	48	14.108	6.5851	.95048	4.9000	31.800	.467	6.000	12.600	25.600
SUPILSF	48	11.340	6.4277	.92776	3.8000	32.600	.567	3.800	10.100	21.300
NRMSITHT	48	87.523	3.2274	.46584	79.900	96.300	.037	83.000	87.300	92.700
TRAGHTS	47	74.247	3.2249	.47040	65.600	82.400	.043	69.800	74.300	79.000
TRAGDPS	47	-.27021	3.0826	.44965	-9.7000	6.0000	-11.408	-4.900	-.300	5.300
BITRGDI	48	13.917	.64917	.93699 -1	12.500	15.400	.047	12.700	14.000	15.000

GLABHTS	48	78.250	3.1543	.45529	71.500	85.900	.040	73.500	78.300	83.200
GLABDPS	48	9.8958	2.7109	.39128	2.5000	15.700	.274	6.100	9.300	15.000
EYELPHTS	48	76.454	3.1813	.45918	68.700	84.400	.042	71.600	76.400	81.400
EYELPDPS	48	8.3396	2.7770	.40083	.80000	14.400	.333	4.800	7.900	13.400
EYELPWDG	48	3.2333	.23820	.34381 -1	2.7000	3.7000	.074	2.800	3.200	3.700
C7HTS	48	63.048	2.9255	.42225	55.500	69.900	.046	58.700	63.100	68.200
C7DPS	48	-9.4458	2.7364	.39497	-17.300	-2.5000	-.290	-12.800	-10.100	-3.400
SSTRNHTS	47	56.153	2.8717	.41888	49.000	61.700	.051	51.000	56.700	59.500
SSTRNDPS	47	3.8298	2.4768	.36128	-1.8000	10.100	.647	.700	3.500	8.900
SHLDRHTS	48	56.719	3.0565	.44117	49.700	62.700	.054	51.800	56.800	61.300
SHLDRDPS	48	-4.4271	2.8352	.40922	-8.7000	2.6000	-.640	-8.400	-4.600	.600
SHLDRBR	48	40.225	2.5091	.36216	36.300	47.500	.062	36.700	39.700	44.900
ILCSPHTS	48	20.281	2.1487	.31014	17.400	28.200	.106	18.200	19.800	26.000
ILCSPDPS	48	11.398	1.4529	.20970	7.7000	14.200	.127	9.100	11.700	13.700
BISPNBR	47	23.726	2.1581	.31480	19.800	29.800	.091	20.600	23.600	27.600
TRCHHTS	48	9.0958	1.4824	.21396	7.0000	14.000	.163	7.200	8.800	11.600
TRCHDPS	48	10.608	1.8163	.26217	7.7000	16.200	.171	7.900	10.100	13.400
BITRCHDI	48	31.906	2.2120	.31927	27.600	36.500	.069	29.400	31.300	35.600
HIPBRSIT	48	36.700	3.5121	.50693	28.700	48.000	.096	30.700	36.800	42.000
ORBHTT	47	.17660	.59315	.86520 -1	-1.2000	1.6000	3.359	-.700	.200	1.000
ORBDPT	47	8.5234	1.3811	.20146	6.8000	11.700	.162	6.900	7.900	10.900
TRAGHTC7	47	11.104	1.2731	.18570	7.9000	13.500	.115	8.800	11.200	13.200
TRAGDPC7	47	9.1489	1.8383	.26815	5.4000	13.100	.201	6.000	9.100	11.500
GLABHTT	47	4.1021	.76938	.11223	2.5000	6.1000	.188	3.000	4.100	5.500
GLABDPT	47	10.232	1.4514	.21171	7.9000	13.500	.142	8.600	9.600	12.700
EYELPHTT	47	2.2979	.59289	.86482 -1	.90000	3.8000	.258	1.400	2.300	3.000
EYELPDPT	47	8.6723	1.3580	.19809	7.0000	11.800	.157	7.100	8.200	11.100
ECTCNATT	47	2.2021	.58141	.84808 -1	.70000	3.6000	.264	1.200	2.200	3.000
ECTCNDPT	47	7.6787	1.3188	.19236	5.9000	10.500	.172	6.200	7.100	10.100
SHLDRSX	48	-4.4271	2.8352	.40922	-8.7000	2.6000	-.640	-8.400	-4.600	.600
SHLDRSY	48	17.642	2.1118	.30481	13.700	22.100	.120	14.100	17.600	21.200
SHLDRSZ	48	56.719	3.0565	.44117	49.700	62.700	.054	51.800	56.800	61.300
C7 SX	48	-9.4458	2.7364	.39497	-17.300	-2.5000	-.290	-12.800	-10.100	-3.400
C7 SY	48	-2.0125	1.3210	.19066	-5.9000	1.0000	-.656	-4.300	-1.800	-.200
C7 SZ	48	63.048	2.9255	.42225	55.500	69.900	.046	58.700	63.100	68.200
SSTRNSX	47	3.8298	2.4768	.36128	-1.8000	10.100	.647	.700	3.500	8.900
SSTRNSY	48	-1.9479	1.2771	.18434	-5.7000	1.0000	-.656	-4.200	-1.800	-.200
SSTRNSZ	47	56.153	2.8717	.41888	49.000	61.700	.051	51.000	56.700	59.500
TRAG SX	47	-.14255	2.7944	.40760	-4.9000	6.0000	-19.602	-4.800	-.300	5.300
TRAG SY	41	6.2293	1.5105	.23590	3.3000	9.6000	.242	3.800	6.300	8.900
TRAG SZ	47	74.247	3.2249	.47040	65.600	82.400	.043	69.800	74.300	79.000
ORBITSX	48	8.1854	2.7555	.39772	.90000	14.300	.337	4.500	7.600	13.400
ORBITSY	48	1.1021	1.5124	.21830	-3.1000	3.7000	1.372	-1.600	1.100	3.200
ORBITSZ	48	74.337	3.2334	.46671	65.900	82.100	.043	69.700	74.300	79.400
GLAB SX	48	9.8958	2.7109	.39128	2.5000	15.700	.274	6.100	9.300	15.000
GLAB SY	48	-2.2750	1.4551	.21002	-6.3000	.60000	-.640	-4.600	-2.400	.200
GLAB SZ	48	78.250	3.1543	.45529	71.500	85.900	.040	73.500	78.300	83.200
EYELPSX	48	8.3396	2.7770	.40083	.80000	14.400	.333	4.800	7.900	13.400
EYELPSY	48	.96458	1.4473	.20890	-3.2000	3.6000	1.500	-1.300	1.000	3.100
EYELPSZ	48	76.454	3.1813	.45918	68.700	84.400	.042	71.600	76.400	81.400
ECCANSX	48	7.3312	2.7444	.39613	0.	13.200	.374	3.700	6.800	12.700
ECCANSY	48	2.3333	1.4635	.21124	-1.9000	4.7000	.627	.100	2.400	4.500
ECCANSZ	48	76.352	3.2025	.46224	68.100	84.400	.042	71.300	76.300	81.300

Table B.4

ANTHROPOMETRY-BY SEX AND AGE-FEMALES, 18-24

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
WT(KG)	16	57.259	6.3145	1.5786	48.182	69.318	.110
WT(LB)	16	125.97	13.892	3.4730	106.00	152.50	.110
STAT(CM)	16	162.26	4.5864	1.1466	155.80	173.70	.028
PONDINDX	16	42.182	1.2191	.30477	40.109	44.086	.029
ERSITHT	16	86.244	2.4221	.60553	82.100	91.100	.028
HEADCIR	16	55.956	1.8301	.45753	53.500	59.100	.033
HEADELPS	16	64.719	1.9205	.48012	62.100	68.800	.030
BITRGDI	16	12.994	.40409	.10102	12.200	13.600	.031
HEADBR	16	14.562	.53401	.13350	13.800	15.300	.037
HEADLG	16	17.937	.64795	.16199	17.100	19.000	.036
SAGARC	16	35.187	1.7806	.44515	32.300	40.100	.051
CORARC	16	34.037	1.4445	.36112	32.000	38.000	.042
BITRGGLB	16	28.456	.95914	.23979	27.000	30.000	.034
BITRGMEN	15	30.333	1.0688	.27597	28.200	32.000	.035
BITRGINA	16	26.125	1.4595	.36486	24.000	29.000	.056
FACEHT	16	12.581	.45785	.11446	11.400	13.300	.036
LATNKBR	16	9.2625	.53526	.13381	8.4000	10.200	.058
APNKBR	16	8.9937	.58705	.14676	8.1000	10.200	.065
SUPNKCIR	16	32.787	2.3593	.58984	30.500	39.500	.072
INFNKCIR	16	36.194	1.9814	.49535	32.800	39.600	.055
POSTNKLG	16	16.794	1.4776	.36940	13.600	18.800	.088
BIACRBR	16	34.650	1.6199	.40497	30.700	37.800	.047
BIDELTBR	16	40.281	2.2239	.55597	35.800	44.300	.055
CHESTHT	15	121.77	3.6706	.94775	116.00	129.90	.030
CHESTBR	15	26.040	1.9335	.49922	23.300	29.300	.074
CHESTCIR	16	83.275	3.9790	.99476	75.800	90.000	.048
WAISTHT	15	100.82	3.7114	.95828	94.400	107.50	.037
WAISTBR	15	23.980	1.8659	.48178	21.500	28.800	.078
WAISTCIR	16	67.600	4.6540	1.1635	60.900	75.300	.069
HIPHT	15	83.900	3.6172	.93396	78.600	91.800	.043
HIPBRSTD	15	32.460	1.7418	.44974	29.100	35.600	.054
HIPCIR	16	95.075	4.9989	1.2497	87.600	104.20	.053
ACRRADLG	16	29.812	1.2633	.31582	26.900	31.700	.042
ARMCIRAX	16	28.012	1.9909	.49773	24.700	31.700	.071
ARMCIREL	16	22.450	1.2204	.30510	20.500	24.800	.054
BICFLCIR	16	26.769	2.1275	.53188	23.900	31.200	.079
RADSTYLG	16	23.069	1.0594	.26485	21.700	25.300	.046
FRARMCIR	16	23.181	1.2502	.31255	20.900	25.200	.054
WRISTCIR	16	15.050	.63351	.15838	14.000	16.200	.042
HANDLG	16	17.162	.58295	.14574	15.800	18.300	.034
TRCFEMLG	15	41.880	2.5208	.65087	36.900	45.200	.060
UPTHICIR	16	57.306	3.9408	.98520	51.200	65.400	.069
LWTHICIR	16	37.587	2.9193	.72983	32.800	42.100	.078
FIBULALG	16	40.525	1.7586	.43965	37.100	42.800	.043
FIBULAHT	16	45.856	2.0874	.52185	42.000	48.900	.046
CALFCIR	16	34.812	2.0736	.51840	31.800	39.400	.060
ANKLECIR	16	20.937	1.1809	.29522	18.700	23.300	.056
FOOTLG	15	23.567	.87069	.22481	22.100	25.200	.037
FOOTBR	15	8.3800	.37455	.96708 -1	7.9000	9.3000	.045
HUMDIA	16	5.9875	.29411	.73527 -1	5.4000	6.4000	.049
FEMDIA	16	8.4437	.33659	.84147 -1	7.8000	9.1000	.040
TRICPSF	16	14.956	5.6513	1.4128	8.2000	29.600	.378
SUBSCPSF	16	14.337	6.4364	1.6091	7.0000	27.200	.449
SUPILSF	16	10.356	4.5759	1.1440	3.5000	18.000	.442
NRMSITHT	16	83.469	2.5418	.63546	80.500	88.100	.030
TRAGHTS	16	70.494	2.4702	.61755	67.600	76.400	.035

TRAGDPS	16	-1.0375	2.8357	.70892	-5.5000	4.3000	-2.733
BITRGDI	16	12.994	.40409	.10102	12.200	13.600	.031
GLABHTS	16	74.319	2.3287	.58218	71.400	79.400	.031
GLABDPS	16	8.3937	3.0132	.75330	3.5000	14.100	.359
EYELPHTS	16	72.687	2.3420	.58551	70.100	77.600	.032
EYELPDPS	16	7.0562	2.8992	.72480	2.2000	12.700	.411
EYELPWDG	16	2.9625	.20616	.51539 -1	2.7000	3.5000	.070
C7HTS	16	59.119	2.3763	.59408	55.400	63.700	.040
C7DPS	16	-9.3375	2.2345	.55863	-12.500	-4.8000	-.239
SSTRNHTS	15	52.973	1.5939	.41156	50.400	56.600	.030
SSTRNDPS	15	1.8533	2.2709	.58634	-1.5000	5.6000	1.225
SHLDRHTS	16	53.044	1.7989	.44972	48.800	55.800	.034
SHLDRDPS	16	-4.1125	2.6333	.65834	-7.2000	2.0000	-.640
SHLDRBR	16	35.600	1.9593	.48981	33.100	40.000	.055
ILCSPHTS	15	19.013	1.4050	.36278	16.300	21.100	.074
ILCSPDPS	15	11.727	1.6246	.41946	8.6000	15.000	.139
BISPNBR	16	22.262	1.8297	.45743	18.500	25.500	.082
TRCHHTS	15	8.4333	.92092	.23778	6.8000	10.400	.109
TRCHDPS	15	9.6933	1.5130	.39066	6.1000	12.400	.156
BITRCHDI	15	29.987	1.4426	.37249	27.400	32.700	.048
HIPBRSIT	15	37.787	2.2894	.59111	34.300	41.300	.061
ORBHTT	16	.26875	.43469	.10867	-.80000	1.0000	1.617
ORBDPT	16	8.0312	.91922	.22980	6.6000	10.600	.114
TRAGHTC7	16	11.387	.96670	.24167	9.6000	12.800	.085
TRAGDPC7	16	8.3187	1.7050	.42625	4.4000	12.300	.205
GLABHTT	16	3.8250	.56627	.14157	2.8000	5.0000	.148
GLABDPT	16	9.4250	1.0440	.26101	7.7000	12.000	.111
EYELPHTT	16	2.1750	.46260	.11565	1.2000	2.9000	.213
EYELPDPT	16	8.0625	.91424	.22856	6.8000	10.600	.113
ECTCNATT	16	2.0687	.50822	.12706	1.0000	2.8000	.246
ECTCNDPT	16	7.0375	.97357	.24339	5.7000	9.8000	.138
SHLDRSX	16	-4.1125	2.6333	.65834	-7.2000	2.0000	-.640
SHLDRSY	16	15.800	1.9552	.48879	12.800	19.200	.124
SHLDRSZ	16	53.044	1.7989	.44972	48.800	55.800	.034
C7 SX	16	-9.3375	2.2345	.55863	-12.500	-4.8000	-.239
C7 SY	16	-1.8187	1.7901	.44751	-5.0000	1.3000	-.984
C7 SZ	16	59.119	2.3763	.59408	55.400	63.700	.040
SSTRNSX	15	1.8533	2.2709	.58634	-1.5000	5.6000	1.225
SSTRNSY	15	-1.7133	1.7860	.46114	-4.8000	1.3000	-1.042
SSTRNSZ	15	52.973	1.5939	.41156	50.400	56.600	.030
TRAG SX	16	-1.0375	2.8357	.70892	-5.5000	4.3000	-2.733
TRAG SY	16	5.8250	1.9550	.48875	2.7000	9.5000	.336
TRAG SZ	16	70.494	2.4702	.61755	67.600	76.400	.035
ORBITSX	16	7.0000	2.8603	.71508	2.1000	12.500	.409
ORBITSY	16	1.1812	1.7886	.44714	-2.2000	5.2000	1.514
ORBITSZ	16	70.775	2.2401	.56002	68.100	75.600	.032
GLAB SX	16	8.3937	3.0132	.75330	3.5000	14.100	.359
GLAB SY	16	-1.8937	1.6659	.41648	-5.1000	1.6000	-.880
GLAB SZ	16	74.319	2.3287	.58218	71.400	79.400	.031
EYELPSX	16	7.0562	2.8992	.72480	2.2000	12.700	.411
EYELPSY	16	1.0750	1.7035	.42588	-2.3000	4.6000	1.585
EYELPSZ	16	72.687	2.3420	.58551	70.100	77.600	.032
ECCANSX	16	5.9875	2.9102	.72755	1.0000	11.600	.486
ECCANSY	16	2.5375	1.7408	.43521	-.80000	6.2000	.686
ECCANSZ	16	72.581	2.3353	.58382	69.800	77.400	.032

Table B.5

ANTHROPOMETRY-BY SEX AND AGE-FEMALES, 35-44

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
WT(KG)	16	59.256	9.5316	2.3829	42.500	83.636	.161
WT(LB)	16	130.36	20.970	5.2424	93.500	184.00	.161
STAT(CM)	16	160.49	5.3844	1.3461	148.50	170.20	.034
PONDINDX	16	41.379	2.4306	.60766	36.249	45.510	.059
ERSITHT	16	85.425	2.4148	.60370	81.500	89.100	.028
HEADCIR	16	55.306	1.3921	.34803	52.600	57.200	.025
HEADELPS	16	63.250	1.4989	.37472	60.400	65.500	.024
BITRGDI	16	13.144	.53162	.13291	12.100	14.300	.040
HEADBR	16	14.775	.33961	.84502 -1	14.300	15.600	023
HEADLG	16	18.019	.57876	.14469	16.800	18.800	.032
SAGARC	16	34.737	1.1483	.28706	32.300	36.800	.033
CORARC	16	33.444	1.1849	.29622	31.200	35.500	.035
BITRGGLB	16	28.356	.76504	.19126	26.700	29.400	.027
BITRGMEN	16	29.656	.88617	.22154	28.000	31.000	.030
BITRGINA	16	25.906	.84654	.21163	24.400	27.400	.033
FACEHT	16	12.212	.54635	.13659	11.200	13.200	.045
LATNKBR	16	9.3312	.62793	.15698	8.4000	10.700	.067
APNKBR	16	9.4125	.60759	.15190	8.5000	10.800	.065
SUPNKCIR	16	33.119	2.1554	.53884	30.400	38.500	.065
INFNKCIR	16	35.406	2.0220	.50551	31.300	39.500	.057
POSTNKLG	16	15.925	1.1602	.29004	13.400	17.400	.073
BIACRBR	16	35.025	1.4130	.35326	32.000	37.800	.040
BIDELTBR	16	41.594	2.4269	.60673	38.400	47.500	.058
CHESTHT	15	122.83	4.5238	1.1680	111.70	131.10	.037
CHESTBR	15	27.633	2.0611	.53217	25.500	32.300	.075
CHESTCIR	16	85.825	5.5732	1.3933	77.800	99.100	.065
WAISTHT	15	100.55	4.9911	1.2887	89.400	110.40	.050
WAISTBR	15	24.493	2.1707	.56048	21.000	29.600	.089
WAISTCIR	16	70.937	6.8828	1.7207	62.200	89.400	.097
HIPHT	15	83.733	4.3814	1.1313	72.700	89.700	.052
HIPBRSTD	14	33.714	2.6970	.72079	29.400	40.800	.080
HIPCIR	16	98.019	8.6391	2.1598	81.800	121.70	.088
ACRRADLG	16	29.831	1.0910	.27275	27.900	32.000	.037
ARMCIRAX	16	29.212	3.3833	.84582	23.800	36.000	.116
ARMCIREL	16	23.306	2.0596	.51490	19.300	27.000	.088
BICFLCIR	16	28.437	2.9547	.73869	23.300	33.800	.104
RADSTYLG	16	22.706	1.0497	.26244	21.000	25.500	.046
FRARMCIR	16	23.306	1.8763	.46908	20.000	25.800	.081
WRISTCIR	16	15.256	.95357	.23839	13.500	16.900	.063
HANDLG	16	17.156	.67722	.16930	16.400	19.100	.039
TRCFEMLG	16	41.694	2.3761	.59403	38.300	45.700	.057
UPTHICIR	16	58.069	5.2491	1.3123	46.800	69.400	.090
LWTHICIR	16	37.637	3.1950	.79874	30.700	44.600	.085
FIBULALG	16	40.194	2.2053	.55132	35.200	44.300	.055
FIBULAHT	16	45.437	2.4215	.60538	40.200	49.700	.053
CALFCIR	16	34.450	2.9310	.73275	29.200	40.300	.085
ANKLECIR	16	20.306	1.1964	.29909	18.300	22.100	.059
FOOTLG	15	23.507	.90354	.23329	22.000	25.200	.038
FOOTBR	15	8.5667	.57776	.14918	7.4000	9.6000	.067
HUMDIA	16	6.0000	.34641	.86603 -1	5.3000	6.5000	.058
FEMDIA	16	8.5875	.56080	.14020	7.7000	9.4000	.065
TRICPSF	16	15.700	4.6120	1.1530	6.9000	23.100	.294
SUBSCPSF	16	15.400	10.919	2.7296	4.4000	44.200	.709
SUPILSF	16	11.519	6.3328	1.5832	2.6000	22.300	.550
NRMSITHT	16	83.344	2.3605	.59012	79.000	87.200	.028
TRAGHTS	14	70.914	2.5295	.67603	65.800	74.600	.036
TRAGDPS	14	-2.8429	2.1461	.57357	-6.9000	.30000	-.755
BITRGDI	16	13.144	.53162	.13291	12.100	14.300	.040

GLABHTS	15	74.507	2.4855	.64176	69.600	78.100	.033
GLABDPS	15	6.2933	2.0155	.52039	2.5000	9.6000	.320
EYELPHTS	15	72.873	2.4930	.64368	68.200	76.500	.034
EYELPDPS	15	5.0267	2.1124	.54541	1.2000	8.3000	.420
EYELPWDG	15	3.0800	.23664	.61101 -1	2.8000	3.6000	.077
C7HTS	16	59.525	2.3136	.57840	55.600	63.400	.039
C7DPS	16	-10.362	2.2556	.56391	-14.400	-4.6000	-.218
SSTRNHTS	13	53.877	2.1514	.59670	49.100	57.800	.040
SSTRNDPS	13	1.6154	2.2196	.61559	-1.9000	5.7000	1.374
SHLDRHTS	16	53.625	2.5000	.62500	48.800	58.700	.047
SHLDRDPS	16	-4.9625	2.0510	.51274	-8.0000	.30000	-.413
SHLDRBR	16	36.406	1.8160	.45401	33.000	39.200	.050
ILCSPHTS	16	19.244	.98791	.24698	17.200	20.800	.051
ILCSPDPS	16	12.056	1.7821	.44553	10.300	16.700	.148
BISPNBR	16	22.606	1.5308	.38270	19.300	24.700	.068
TRCHHTS	16	8.3125	1.4619	.36548	6.6000	12.000	.176
TRCHDPS	15	10.020	1.6678	.43064	6.7000	12.900	.166
BITRCHDI	16	31.062	1.2753	.31884	28.700	33.100	.041
HIPBRSIT	16	39.231	3.4090	.85224	31.700	46.100	.087
ORBHTT	14	.33571	.66634	.17809	-.40000	1.9000	1.985
ORBDPT	14	7.5429	.90615	.24218	5.9000	9.9000	.120
TRAGHTC7	14	11.593	1.1056	.29547	8.9000	13.100	.095
TRAGDPC7	14	8.0500	1.4501	.38755	5.8000	11.200	.180
GLABHTT	14	3.6929	.64147	.17144	2.5000	4.7000	.174
GLABDPT	14	8.9000	.96317	.25742	7.3000	10.800	.108
EYELPHTT	14	2.0786	.51168	.13675	.80000	2.7000	.246
EYELPDPT	14	7.6357	.96525	.25797	6.1000	10.000	.126
ECTCNATT	14	2.0286	.52393	.14003	.80000	2.9000	.258
ECTCNDPT	14	6.6714	.96829	.25879	5.2000	9.1000	.145
SHLDRSX	16	-4.9625	2.0510	.51274	-8.0000	.30000	-.413
SHLDRSY	16	16.050	1.5958	.39896	12.600	18.400	.099
SHLDRSZ	16	53.625	2.5000	.62500	48.800	58.700	.047
C7 SX	16	-10.362	2.2556	.56391	-14.400	-4.6000	-.218
C7 SY	16	-2.0812	1.4721	.36801	-4.6000	.70000	-.707
C7 SZ	16	59.525	2.3136	.57840	55.600	63.400	.039
SSTRNSX	13	1.6154	2.2196	.61559	-1.9000	5.7000	1.374
SSTRNSY	16	-2.0187	1.4209	.35523	-4.5000	.70000	-.704
SSTRNSZ	13	53.877	2.1514	.59670	49.100	57.800	.040
TRAG SX	14	-2.8429	2.1461	.57357	-6.9000	.30000	-.755
TRAG SY	13	5.4846	1.7911	.49676	2.4000	9.0000	.327
TRAG SZ	14	70.914	2.5295	.67603	65.800	74.600	.036
ORBITSX	15	4.9400	2.1404	.55264	1.0000	8.3000	.433
ORBITSY	15	.85333	1.7764	.45866	-2.5000	4.9000	2.082
ORBITSZ	15	71.113	2.2545	.58210	67.800	74.500	.032
GLAB SX	15	6.2933	2.0155	.52039	2.5000	9.6000	.320
GLAB SY	15	-2.2933	1.8691	.48260	-6.1000	1.8000	-.815
GLAB SZ	15	74.507	2.4855	.64176	69.600	78.100	.033
EYELPSX	15	5.0267	2.1124	.54541	1.2000	8.3000	.420
EYELPSY	15	.79333	1.7401	.44928	-2.8000	4.6000	2.193
EYELPSZ	15	72.873	2.4930	.64368	68.200	76.500	.034
ECCANSX	15	4.0800	2.1789	.56258	.10000	7.5000	.534
ECCANSY	15	2.1733	1.7926	.46286	-1.7000	6.0000	.825
ECCANSZ	15	72.833	2.5122	.64864	68.100	76.400	.034

Table B.6

ANTHROPOMETRY-BY SEX AND AGE-FEMALES, 62-74

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
WT(KG)	16	66.023	12.546	3.1364	51.818	94.091	.190
WT(LB)	16	145.25	27.601	6.9002	114.00	207.00	.190
STAT(CM)	16	156.29	5.6536	1.4134	145.50	167.30	.036
PONDINDX	16	38.909	2.1626	.54066	34.783	42.966	.056
ERSITHT	16	82.031	3.4343	.85857	76.600	89.300	.042
HEADCIR	16	55.837	1.5786	.39464	53.800	58.200	.028
HEADELPS	16	64.637	1.8906	.47266	61.400	67.700	.029
BITRGDI	16	13.537	.52393	.13098	12.200	14.300	.039
HEADBR	16	15.012	.47732	.11933	14.200	15.800	.032
HEADLG	16	18.125	.60828	.15207	17.300	19.200	.034
SAGARC	16	34.212	1.2044	.30109	32.400	36.300	.035
CORARC	16	34.356	1.3947	.34868	32.200	36.800	.041
BITRGGLB	16	28.919	.92680	.23170	27.300	31.000	.032
BITRGMEN	16	30.162	1.3544	.33861	28.500	32.200	.045
BITRGINA	16	26.619	1.0678	.26696	24.800	28.500	.040
FACEHT	16	12.519	.57760	.14440	11.600	13.400	.046
LATNKBR	16	9.5312	.77004	.19251	8.6000	11.200	.081
APNKBR	16	10.319	.90937	.22734	9.0000	12.800	.088
SUPNKCIR	16	35.912	3.4060	.85151	30.500	43.200	.095
INFNKCIR	16	37.987	2.6435	.66086	33.500	42.200	.070
POSTNKLG	16	14.000	1.5297	.38243	11.500	16.800	.109
BIACRBR	16	34.562	2.1023	.52558	30.400	38.400	.061
BIDELTBR	16	41.956	3.5251	.88129	38.600	49.300	.084
CHESTHT	16	117.87	5.1275	1.2819	107.50	127.20	.044
CHESTBR	16	28.819	2.7552	.68879	24.600	33.700	.096
CHESTCIR	15	90.673	6.6747	1.7234	82.700	104.20	.074
WAISTHT	16	98.175	3.9357	.98393	89.000	104.60	.040
WAISTBR	16	27.012	2.7626	.69064	23.200	33.000	.102
WAISTCIR	15	82.393	9.0841	2.3455	68.400	99.300	.110
HIPHT	15	83.700	4.3215	1.1158	72.700	88.600	.052
HIPBRSTD	16	35.862	3.1544	.78861	32.100	43.000	.088
HIPCIR	15	103.70	11.954	3.0864	83.800	127.80	.115
ACRRADLG	16	30.069	1.3573	.33933	27.600	31.800	.045
ARMCIRAX	16	31.131	3.4255	.85638	26.900	38.600	.110
ARMCIREL	16	25.512	3.2623	.81557	21.300	32.400	.128
BICFLCIR	16	30.906	4.1594	1.0399	24.700	39.300	.135
RADSTYLG	16	21.900	1.0627	.26568	19.200	23.400	.049
FRARMCIR	16	24.069	2.0908	.52271	21.500	28.000	.087
WRISTCIR	16	16.356	1.7810	.44525	14.600	20.200	.109
HANDLG	16	16.912	.74554	.18639	15.900	18.200	.044
TRCFEMLG	14	42.179	2.3179	.61948	37.900	46.600	.055
UPTHICIR	15	61.487	7.6536	1.9761	47.300	77.700	.124
LWTHICIR	16	39.887	4.6003	1.1501	33.600	50.100	.115
FIBULALG	16	39.644	2.3131	.57829	35.000	43.000	.058
FIBULAHT	16	44.856	2.3149	.57872	40.100	47.800	.052
CALFCIR	16	35.225	3.2107	.80268	29.800	42.200	.091
ANKLECIR	16	21.075	1.2933	.32333	18.200	22.300	.061
FOOTLG	16	23.169	1.1447	.28617	20.200	24.900	.049
FOOTBR	16	8.7375	.61847	.15462	7.8000	9.7000	.071
HUMDIA	16	6.1937	.43431	.10858	5.4000	7.3000	.070
FEMDIA	15	8.5533	.63343	.16355	7.4000	9.9000	.074
TRICPSF	16	21.094	9.1706	2.2926	6.8000	33.700	.435
SUBSCPSF	16	21.494	9.7083	2.4271	8.1000	38.800	.452
SUPILSF	16	18.344	6.9602	1.7400	7.9000	31.000	.379
NRMSITHT	16	79.394	3.2689	.81723	73.300	85.900	.041
TRAGHTS	15	66.853	3.0979	.79987	62.200	72.200	.046
TRAGDPS	15	-.54667	2.7399	.70743	-4.8000	4.6000	-5.012
BITRGDI	16	13.537	.52393	.13098	12.200	14.300	.039

GLABHTS	16	71.125	3.1263	.78158		66.000	76.700	.044
GLABDPS	16	9.0500	2.4036	.60090		4.2000	14.100	.266
EYELPHTS	16	69.356	3.0369	.75922		64.700	75.100	.044
EYELPDPS	16	7.7187	2.4216	.60541		2.8000	12.600	.314
EYELPWDG	16	3.1750	.31091	.77728	-1	2.7000	3.8000	.098
C7HTS	15	57.247	2.2784	.58829		52.600	61.200	.040
C7DPS	15	-8.9267	1.9670	.50789		-11.900	-5.0000	-.220
SSTRNHTS	16	51.031	2.5408	.63520		46.600	56.300	.050
SSTRNDPS	16	4.4187	1.8295	.45737		1.2000	7.3000	.414
SHLDRHTS	16	50.869	2.2945	.57364		45.800	54.400	.045
SHLDRDPS	16	-3.2187	2.8963	.72406		-8.8000	1.3000	-.900
SHLDRBR	16	35.244	1.8608	.46520		33.100	40.300	.053
ILCSPHTS	16	19.231	.99312	.24828		17.600	21.300	.052
ILCSPDPS	15	13.867	1.8772	.48469		11.000	17.800	.135
BISPNBR	16	24.306	1.5163	.37909		22.200	27.200	.062
TRCHHTS	13	9.2077	1.5494	.42974		7.0000	12.900	.168
TRCHDPS	13	10.662	2.0569	.57049		7.4000	14.400	.193
BITRCHDI	16	32.150	2.7539	.68848		27.400	38.700	.086
HIPBRSIT	16	40.800	4.8530	1.2133		34.600	49.800	.119
ORBHTT	15	.72667	.48028	.12401		-.10000	1.8000	.661
ORBDPT	15	8.1600	1.3516	.34898		6.6000	11.600	.166
TRAGHTC7	14	9.8357	1.4194	.37936		7.9000	13.500	.144
TRAGDPC7	14	8.1357	1.6189	.43268		4.8000	10.300	.199
GLABHTT	15	4.3267	.61350	.15840		3.5000	6.1000	.142
GLABDPT	15	9.4867	1.3711	.35401		7.7000	13.200	.145
EYELPHTT	15	2.5133	.35429	.91478	-1	1.9000	3.2000	.141
EYELPDPT	15	8.1467	1.2305	.31771		6.9000	11.200	.151
ECTCNATT	15	2.4267	.31275	.80750	-1	1.8000	3.1000	.129
ECTCNDPT	15	7.2533	1.2287	.31726		6.1000	10.400	.169
SHLDRSX	16	-3.2187	2.8963	.72406		-8.8000	1.3000	-.900
SHLDRSY	16	14.694	2.2389	.55972		11.300	19.700	.152
SHLDRSZ	16	50.869	2.2945	.57364		45.800	54.400	.045
C7 SX	15	-8.9267	1.9670	.50789		-11.900	-5.0000	-.220
C7 SY	16	-2.1312	1.2929	.32323		-3.9000	-.10000	-.607
C7 SZ	15	57.247	2.2784	.58829		52.600	61.200	.040
SSTRNSX	16	4.4187	1.8295	.45737		1.2000	7.3000	.414
SSTRNSY	16	-2.0562	1.2495	.31238		-3.8000	-.10000	-.608
SSTRNSZ	16	51.031	2.5408	.63520		46.600	56.300	.050
TRAG SX	15	-.54667	2.7399	.70743		-4.8000	4.6000	-5.012
TRAG SY	13	5.9308	1.5882	.44048		3.2000	8.9000	.268
TRAG SZ	15	66.853	3.0979	.79987		62.200	72.200	.046
ORBITSX	16	7.7500	2.3048	.57619		3.1000	12.100	.297
ORBITSY	16	.78750	1.5279	.38198		-1.4000	3.7000	1.940
ORBITSZ	16	67.600	3.0546	.76365		62.900	73.000	.045
GLAB SX	16	9.0500	2.4036	.60090		4.2000	14.100	.266
GLAB SY	16	-2.5562	1.5262	.38155		-5.0000	.40000	-.597
GLAB SZ	16	71.125	3.1263	.78158		66.000	76.700	.044
EYELPSX	16	7.7187	2.4216	.60541		2.8000	12.600	.314
EYELPSY	16	.63125	1.5041	.37602		-1.2000	3.5000	2.383
EYELPSZ	16	69.356	3.0369	.75922		64.700	75.100	.044
ECCANSX	16	6.8500	2.4380	.60951		2.1000	11.800	.356
ECCANSY	16	1.9250	1.5442	.38606		.20000	5.0000	.802
ECCANSZ	16	69.281	3.0072	.75179		64.700	74.800	.043

Table B.7

ANTHROPOMETRY-BY SEX AND AGE-MALES, 18-24

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
WT(KG)	17	71.591	12.673	3.0737	54.318	103.64	.177
WT(LB)	17	157.50	27.881	6.7621	119.50	228.00	.177
STAT(CM)	17	174.95	5.7985	1.4063	165.90	186.40	.033
PONDINDX	17	42.343	1.6407	.39793	39.323	45.290	.039
ERSITHT	17	91.518	3.1801	.77128	86.500	97.300	.035
HEADCIR	17	58.635	1.7080	.41426	55.800	62.300	.029
HEADELPS	17	67.588	2.6986	.65450	62.600	71.800	.040
BITRGDI	17	13.518	.56262	.13646	12.500	14.400	.042
HEADBR	17	15.112	.57542	.13956	14.100	16.000	.038
HEADLG	17	19.318	.69123	.16765	18.100	20.700	.036
SAGARC	17	36.706	1.2572	.30492	34.500	38.700	.034
CORARC	17	35.882	1.3794	.33456	33.600	38.000	.038
BITRGGLB	17	30.282	1.2151	.29471	28.000	32.600	.040
BITRGMEN	17	32.147	1.6398	.39771	29.100	34.400	.051
BITRGINA	17	27.724	1.6411	.39802	25.000	32.000	.059
FACEHT	17	13.482	.77881	.18889	12.500	15.000	.058
LATNKBR	17	10.994	.94569	.22936	9.6000	13.200	.086
APNKBR	17	10.553	.69112	.16762	9.5000	12.400	.065
SUPNKCIR	17	37.229	2.3056	.55920	34.300	43.800	.062
INFNKCIR	17	40.606	1.9476	.47236	38.000	45.900	.048
POSTNKLG	17	17.176	1.5534	.37676	14.700	20.000	.090
BIACRBR	17	39.559	2.8959	.70236	33.900	44.200	.073
BIDELTBR	17	46.412	3.3174	.80458	40.200	52.700	.071
CHESTHT	16	131.32	3.8065	.95163	122.90	138.50	.029
CHESTBR	16	31.444	2.6321	.65803	27.200	37.100	.084
CHESTCIR	16	94.900	5.2940	1.3235	86.000	102.30	.056
WAISTHT	16	105.92	5.3701	1.3425	99.500	118.80	.051
WAISTBR	16	28.869	3.2922	.82304	24.000	36.900	.114
WAISTCIR	17	80.206	7.9901	1.9379	67.700	97.600	.100
HIPHT	16	90.325	3.8976	.97440	83.100	98.800	.043
HIPBRSTD	16	33.775	2.2746	.56866	30.900	38.000	.067
HIPCIR	17	96.147	7.4499	1.8069	86.500	111.30	.077
ACRRADLG	17	32.771	1.7624	.42744	29.400	36.200	.054
ARMCIRAX	17	31.753	3.0266	.73405	25.800	39.100	.095
ARMCIREL	17	25.282	1.8789	.45570	22.600	30.000	.074
BICFLCIR	17	31.376	2.7401	.66457	27.500	38.200	.087
RADSTYLG	17	25.476	1.1037	.26769	23.100	27.400	.043
FRARMCIR	17	26.988	1.6109	.39069	24.900	31.000	.060
WRISTCIR	17	16.994	1.1808	.28639	14.900	20.000	.069
HANDLG	17	18.953	.75673	.18354	17.500	20.400	.040
TRCFEMLG	17	42.482	2.3421	.56804	37.900	46.800	.055
UPTHICIR	17	56.600	6.3388	1.5374	46.300	67.300	.112
LWTHICIR	17	38.588	3.1094	.75415	32.500	44.500	.081
FIBULALG	17	44.400	2.4081	.58404	40.600	50.100	.054
FIBULAHT	17	50.776	2.5731	.62406	47.200	56.500	.051
CALFCIR	17	36.706	2.6729	.64827	31.000	43.500	.073
ANKLECIR	17	22.518	1.1891	.28841	20.200	25.200	.053
FOOTLG	16	26.387	1.5050	.37626	24.200	29.000	.057
FOOTBR	16	9.5062	.47815	.11954	8.7000	10.200	.050
HUMDIA	17	7.0294	.51813	.12566	6.3000	8.4000	.074
FEMDIA	17	9.2588	.67921	.16473	7.8000	10.400	.073
TRICPSF	17	7.8647	3.5619	.86390	3.9000	15.300	.453
SUBSCPSF	17	10.876	5.9005	1.4311	5.5000	25.600	.542
SUPILSF	17	9.5118	7.1290	1.7290	3.8000	32.600	.749
NRMSITHT	17	88.935	3.4260	.83093	83.300	96.300	.039
TRAGHTS	17	75.153	3.5859	.86972	69.800	82.400	.048
TRAGDPS	17	-1.2235	3.7484	.90913	-9.7000	6.0000	-3.064
BITRGDI	17	13.518	.56262	.13646	12.500	14.400	.042

GLABHTS	17	79.094	3.4584	.83879	74.000	85.900	.044
GLABDPS	17	9.3706	2.8561	.69270	2.5000	15.700	.305
EYELPHTS	17	77.371	3.4541	.83775	72.600	84.400	.045
EYELPDPS	17	7.5765	2.9320	.71113	.80000	14.300	.387
EYELPWDG	17	3.2647	.23168	.56191 -1	2.7000	3.7000	.071
C7HTS	17	63.288	3.3429	.81077	59.000	69.900	.053
C7DPS	17	-10.229	3.2105	.77866	-17.300	-2.5000	-.314
SSTRNHTS	17	56.265	3.5375	.85796	50.500	61.700	.063
SSTRNDPS	17	2.3059	2.1528	.52212	-1.8000	7.7000	.934
SHLDRHTS	17	56.824	3.7082	.89937	51.800	62.700	.065
SHLDRDPS	17	-5.4176	2.7884	.67629	-8.7000	-.20000	-.515
SHLDRBR	17	41.506	2.3253	.56396	37.800	45.800	.056
ILCSPHTS	17	21.171	2.7269	.66137	18.300	28.200	.129
ILCSPDPS	17	10.418	1.4825	.35956	7.7000	12.600	.142
BISPNBR	17	23.176	1.8913	.45870	19.800	27.600	.082
TRCHHTS	17	9.5529	1.3830	.33542	7.1000	12.900	.145
TRCHDPS	17	11.112	2.1242	.51520	7.8000	16.200	.191
BITRCHDI	17	31.465	2.3714	.57516	27.600	36.500	.075
HIPBRSIT	17	36.465	4.8376	1.1733	28.700	48.000	.133
ORBHTT	17	.88235 -1	.46755	.11340	-.70000	.70000	5.299
ORBDPT	17	8.6647	1.4820	.35943	6.8000	11.300	.171
TRAGHTC7	17	11.871	.84466	.20486	10.400	13.500	.071
TRAGDPC7	17	9.0176	2.0492	.49699	5.4000	13.100	.227
GLABHTT	17	3.9294	.58498	.14188	3.0000	5.1000	.149
GLABDPT	17	10.565	1.6390	.39751	8.4000	13.500	.155
EYELPHTT	17	2.1941	.41754	.10127	1.4000	2.9000	.190
EYELPDPT	17	8.7706	1.4256	.34575	7.0000	11.300	.163
ECTCNATT	17	2.1647	.43866	.10639	1.4000	3.0000	.203
ECTCNDPT	17	7.7471	1.3807	.33487	6.2000	10.200	.178
SHLDRSX	17	-5.4176	2.7884	.67629	-8.7000	-.20000	-.515
SHLDRSY	17	18.259	2.4533	.59502	13.700	22.000	.134
SHLDRSZ	17	56.824	3.7082	.89937	51.800	62.700	.065
C7 SX	17	-10.229	3.2105	.77866	-17.300	-2.5000	-.314
C7 SY	17	-1.9176	1.6307	.39549	-5.9000	1.0000	-.850
C7 SZ	17	63.288	3.3429	.81077	59.000	69.900	.053
SSTRNSX	17	2.3059	2.1528	.52212	-1.8000	7.7000	.934
SSTRNSY	17	-1.8529	1.5832	.38397	-5.7000	1.0000	-.854
SSTRNSZ	17	56.265	3.5375	.85796	50.500	61.700	.063
TRAG SX	17	-.87059	3.1322	.75968	-4.9000	6.0000	-3.598
TRAG SY	15	6.5333	1.4936	.38566	3.8000	9.0000	.229
TRAG SZ	17	75.153	3.5859	.86972	69.800	82.400	.048
ORBITSX	17	7.4529	2.9033	.70414	.90000	13.900	.390
ORBITSY	17	1.3588	1.5823	.38378	-3.1000	3.2000	1.164
ORBITSZ	17	75.259	3.3871	.82150	69.900	82.100	.045
GLAB SX	17	9.3706	2.8561	.69270	2.5000	15.700	.305
GLAB SY	17	-2.0706	1.5111	.36650	-6.3000	.20000	-.730
GLAB SZ	17	79.094	3.4584	.83879	74.000	85.900	.044
EYELPSX	17	7.5765	2.9320	.71113	.80000	14.300	.387
EYELPSY	17	1.1824	1.5521	.37644	-3.2000	3.4000	1.313
EYELPSZ	17	77.371	3.4541	.83775	72.600	84.400	.045
ECCANSX	17	6.5471	2.8977	.70278	0.	13.200	.443
ECCANSY	17	2.6000	1.5803	.38329	-1.9000	4.7000	.608
ECCANSZ	17	77.329	3.4174	.82884	72.800	84.400	.044

Table B.8 ANTHROPOMETRY-BY SEX AND AGE-MALES, 35-44

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
WT(KG)	15	78.506	6.3198	1.6318	68.636	91.136	.081
WT(LB)	15	172.71	13.934	3.5899	151.00	200.50	.081
STAT(CM)	15	173.70	6.8205	1.7610	159.80	186.10	.039
PONDINDX	15	40.615	1.6549	.42730	37.898	44.385	.041
ERSITHT	15	89.747	3.5930	.92771	84.500	96.000	.040
HEADCIR	15	58.107	1.2355	.31900	55.900	60.500	.021
HEADELPS	15	67.353	1.4793	.38196	64.500	69.500	.022
BITRGDI	15	13.980	.53878	.13911	13.000	15.200	.039
HEADBR	15	15.393	.69536	.17954	14.300	16.700	.045
HEADLG	15	19.087	.56425	.14569	18.200	20.100	.030
SAGARC	15	35.453	1.2822	.33107	32.800	37.300	.036
CORARC	15	35.320	1.4551	.37572	32.700	37.800	.041
BITRGGLB	15	29.973	.82068	.21190	28.000	31.000	.027
BITRGMEN	15	32.520	.91978	.23749	30.500	34.500	.028
BITRGINA	15	27.893	.93310	.24092	25.700	29.100	.033
FACEHT	15	13.387	.65994	.17040	12.000	14.700	.049
LATNKBR	15	10.807	.82848	.21391	9.4000	12.000	.077
APNKBR	15	11.093	.73043	.18860	10.000	12.900	.066
SUPNKCIR	15	40.320	2.8130	.72632	35.500	46.200	.070
INFNKCIR	14	41.514	2.4701	.66016	38.200	45.500	.059
POSTNKLG	15	16.620	1.0269	.26515	15.000	18.500	.062
BIACRBR	14	39.029	2.0170	.53907	36.000	43.000	.052
BIDELTBR	15	46.767	3.0900	.79783	38.300	52.400	.066
CHESTHT	15	131.33	5.5708	1.4384	121.40	140.80	.042
CHESTBR	15	32.033	1.5963	.41216	30.100	35.700	.050
CHESTCIR	14	101.01	4.7514	1.2699	90.500	108.10	.047
WAISTHT	15	104.35	5.6084	1.4481	93.200	114.60	.054
WAISTBR	15	30.353	1.6733	.43203	27.400	32.500	.055
WAISTCIR	14	88.571	5.1962	1.3887	79.300	96.000	.059
HIPHT	15	91.340	4.3270	1.1172	82.000	98.300	.047
HIPBRSTD	15	34.327	1.3419	.34647	32.400	36.600	.039
HIPCIR	15	100.63	3.5261	.91044	93.000	108.00	.035
ACRRADLG	15	33.613	2.1653	.55907	30.600	37.700	.064
ARMCIRAX	15	33.547	1.8130	.46811	29.400	36.300	.054
ARMCIREL	15	26.713	1.5592	.40259	23.700	28.700	.058
BICFLCIR	15	33.193	2.4537	.63354	27.800	38.200	.074
RADSTYLG	15	25.747	1.3809	.35655	23.200	28.200	.054
FRARMCIR	15	27.827	2.0359	.52567	24.900	31.400	.073
WRISTCIR	15	17.513	1.2374	.31950	15.300	19.600	.071
HANDLG	15	18.613	1.1300	.29177	17.000	21.600	.061
TRCFEMLG	15	44.220	2.6135	.67480	38.800	48.500	.059
UPTHICIR	15	58.527	4.6086	1.1899	51.300	67.500	.079
LWTHICIR	15	40.133	1.6944	.43749	36.300	42.700	.042
FIBULALG	15	44.620	2.3103	.59651	40.700	48.600	.052
FIBULAHT	15	50.813	2.4245	.62601	46.800	54.700	.048
CALFCIR	15	36.840	1.8928	.48871	34.200	41.200	.051
ANKLECIR	15	22.127	1.0918	.28191	20.800	24.500	.049
FOOTLG	15	26.140	1.4252	.36798	24.300	29.600	.055
FOOTBR	15	9.5667	.65320	.16865	8.5000	11.000	.068
HUMDIA	15	7.1133	.66533	.17179	6.3000	8.9000	.094
FEMDIA	15	9.6067	.52300	.13504	8.8000	10.600	.054
TRICPSF	15	10.360	3.8336	.98984	5.6000	17.500	.370
SUBSCPSF	15	18.653	6.6393	1.7143	8.2000	31.800	.356
SUPILSF	15	15.200	5.8912	1.5211	4.5000	25.700	.388
NRMSITHT	15	86.867	3.1084	.80259	82.400	92.700	.036
TRAGHTS	15	73.860	2.9729	.76761	68.600	79.000	.040
TRAGDPS	15	-.18000	2.4507	.63277	-3.6000	4.3000	-13.615
BITRGDI	15	13.980	.53878	.13911	13.000	15.200	.039

GLABHTS	15	78.013	3.0799	.79522	73.500	83.200	.039
GLABDPS	15	9.9933	2.5767	.66529	6.1000	15.400	.258
EYELPHTS	15	76.180	3.0417	.78535	71.400	81.400	.040
EYELPDPS	15	8.6267	2.6059	.67284	4.8000	14.400	.302
EYELPWDG	15	3.2333	.24976	.64488 -1	2.8000	3.7000	.077
C7HTS	15	62.900	2.6517	.68466	58.700	67.200	.042
C7DPS	15	-9.1333	2.5261	.65222	-12.800	-3.4000	-.277
SSTRNHTS	14	56.250	2.3177	.61944	51.000	59.300	.041
SSTRNDPS	14	4.3571	2.2816	.60978	1.9000	9.0000	.524
SHLDRHTS	15	57.120	2.4190	.62459	51.800	60.500	.042
SHLDRDPS	15	-3.5600	3.1227	.80627	-8.4000	2.6000	-.877
SHLDRBR	15	40.700	2.6568	.68598	37.000	47.500	.065
ILCSPHTS	15	20.047	1.0710	.27652	18.500	22.200	.053
ILCSPDPS	15	11.733	.97663	.25217	10.200	13.600	.083
BISPNBR	14	22.857	1.8146	.48502	20.100	26.000	.079
TRCHHTS	15	9.3067	1.0971	.28326	7.9000	11.600	.118
TRCHDPS	15	10.313	1.3653	.35252	7.9000	12.400	.132
BITRCHDI	15	31.213	1.9777	.51064	28.500	35.300	.063
HIPBRSIT	15	37.693	3.1662	.81751	30.700	45.200	.084
ORBHTT	15	.18667	.59506	.15364	-.70000	1.6000	3.188
ORBDPT	15	8.6067	1.5299	.39502	6.9000	11.700	.178
TRAGHTC7	15	10.960	.95902	.24762	8.8000	12.700	.088
TRAGDPC7	15	8.9467	1.9464	.50255	5.9000	12.700	.218
GLABHTT	15	4.1533	.74438	.19220	3.0000	6.1000	.179
GLABDPT	15	10.187	1.5118	.39034	7.9000	12.900	.148
EYELPHTT	15	2.3067	.68709	.17741	.90000	3.7000	.298
EYELPDPT	15	8.8067	1.5337	.39599	7.0000	11.800	.174
ECTCNATT	15	2.2000	.70912	.18310	.70000	3.6000	.322
ECTCNDPT	15	7.8067	1.4675	.37890	5.9000	10.500	.188
SHLDRSX	15	-3.5600	3.1227	.80627	-8.4000	2.6000	-.877
SHLDRSY	15	18.160	1.8106	.46750	14.800	22.100	.100
SHLDRSZ	15	57.120	2.4190	.62459	51.800	60.500	.042
C7 SX	15	-9.1333	2.5261	.65222	-12.800	-3.4000	-.277
C7 SY	15	-1.9467	.92340	.23842	-3.7000	-.70000	-.474
C7 SZ	15	62.900	2.6517	.68466	58.700	67.200	.042
SSTRNSX	14	4.3571	2.2816	.60978	1.9000	9.0000	.524
SSTRNSY	15	-1.8933	.88678	.22897	-3.5000	-.70000	-.468
SSTRNSZ	14	56.250	2.3177	.61944	51.000	59.300	.041
TRAG SX	15	-.18000	2.4507	.63277	-3.6000	4.3000	-13.615
TRAG SY	13	6.1846	1.7925	.49715	3.3000	9.6000	.290
TRAG SZ	15	73.860	2.9729	.76761	68.600	79.000	.040
ORBITSX	15	8.4200	2.5532	.65923	4.9000	14.300	.303
ORBITSY	15	.88667	1.3543	.34968	-1.2000	3.2000	1.527
ORBITSZ	15	74.060	3.1731	.81928	69.200	79.400	.043
GLAB SX	15	9.9933	2.5767	.66529	6.1000	15.400	.258
GLAB SY	15	-2.4467	1.3109	.33847	-4.1000	.20000	-.536
GLAB SZ	15	78.013	3.0799	.79522	73.500	83.200	.039
EYELPSX	15	8.6267	2.6059	.67284	4.8000	14.400	.302
EYELPSY	15	.79333	1.2646	.32652	-1.3000	3.1000	1.594
EYELPSZ	15	76.180	3.0417	.78535	71.400	81.400	.040
ECCANSX	15	7.5933	2.5720	.66408	3.9000	13.100	.339
ECCANSY	15	2.1800	1.3192	.34062	.10000	4.5000	.605
ECCANSZ	15	76.073	3.0330	.78312	71.300	81.300	.040

Table B.9

ANTHROPOMETRY-BY SEX AND AGE-MALES, 62-74

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
WT(KG)	16	70.682	7.8383	1.9596	60.227	84.318	.111
WT(LB)	16	155.50	17.244	4.3111	132.50	185.50	.111
STAT(CM)	16	169.79	4.5057	1.1264	163.40	180.20	.027
PONDINDX	16	41.168	1.7127	.42818	38.409	43.699	.042
ERSITHT	16	88.781	2.4323	.60809	84.000	94.100	.027
HEADCIR	16	58.112	1.7274	.43184	54.700	60.800	.030
HEADELPS	16	67.137	1.7412	.43530	63.800	70.000	.026
BITRGDI	16	14.281	.62099	.15525	13.200	15.400	.043
HEADBR	16	15.612	.49917	.12479	14.800	16.600	.032
HEADLG	16	18.912	.86554	.21639	17.500	20.900	.046
SAGARC	16	35.456	1.3140	.32850	32.500	37.900	.037
CORARC	16	34.462	1.3341	.33353	31.500	37.000	.039
BITRGGLB	16	29.900	1.4656	.36640	27.300	33.200	.049
BITRGMEN	16	32.694	1.4350	.35876	30.200	35.500	.044
BITRGINA	16	27.306	.97260	.24315	24.800	28.300	.036
FACEHT	16	13.287	.71636	.17909	12.000	14.300	.054
LATNKBR	16	10.525	.89331	.22333	9.3000	12.300	.085
APNKBR	16	11.812	.78983	.19746	10.200	13.700	.067
SUPNKCIR	16	41.356	3.0470	.76174	35.700	46.900	.074
INFNKCIR	16	40.181	2.7120	.67800	32.000	44.400	.067
POSTNKLG	16	15.175	1.4210	.35526	13.500	18.500	.094
BIACRBR	16	37.125	2.1956	.54890	32.300	40.000	.059
BIDELTBR	16	43.850	2.3475	.58687	38.700	47.900	.054
CHESTHT	16	127.75	4.0887	1.0222	120.50	136.50	.032
CHESTBR	16	31.156	2.6668	.66671	28.000	38.400	.086
CHESTCIR	16	96.050	4.9364	1.2341	87.400	105.20	.051
WAISTHT	16	103.36	4.7214	1.1804	97.500	112.00	.046
WAISTBR	16	29.000	3.0675	.76687	20.700	34.600	.106
WAISTCIR	16	89.644	8.7813	2.1953	80.500	108.50	.098
HIPHT	15	90.080	3.0370	.78414	86.200	95.200	.034
HIPBRSTD	16	33.987	1.3391	.33477	31.800	36.600	.039
HIPCIR	16	97.506	4.7492	1.1873	89.400	104.50	.049
ACRRADLG	16	32.575	1.5049	.37622	29.400	34.900	.046
ARMCIRAX	16	31.512	2.2494	.56235	27.400	36.000	.071
ARMCIREL	16	24.775	1.6751	.41878	21.900	27.300	.068
BICFLCIR	16	31.387	2.8095	.70237	26.500	35.700	.090
RADSTYLG	16	24.712	1.2574	.31436	22.500	27.000	.051
FRARMCIR	16	26.144	1.9256	.48140	23.000	28.700	.074
WRISTCIR	16	17.200	1.3633	.34083	15.400	20.000	.079
HANDLG	16	18.456	.63348	.15837	17.300	19.600	.034
TRCFEMLG	16	42.231	2.2559	.56397	36.300	45.800	.053
UPTHICIR	16	53.556	3.2480	.81199	48.400	58.900	.061
LWTHICIR	16	37.469	2.7163	.67908	33.500	43.700	.072
FIBULALG	16	44.037	1.7511	.43779	40.200	46.800	.040
FIBULAHT	16	49.481	1.7792	.44481	46.500	52.200	.036
CALFCIR	16	34.812	1.8913	.47283	31.300	38.500	.054
ANKLECIR	16	21.975	1.2482	.31205	20.300	24.800	.057
FOOTLG	16	25.731	1.1104	.27760	23.800	28.100	.043
FOOTBR	16	9.4437	.58420	.14605	8.5000	10.400	.062
HUMDIA	16	7.0375	.63127	.15782	5.9000	8.8000	.090
FEMDIA	16	9.3000	.65929	.16482	8.4000	10.700	.071
TRICPSF	16	9.0562	4.4615	1.1154	4.5000	21.600	.493
SUBSCPSF	16	13.281	4.9367	1.2342	4.9000	23.300	.372
SUPILSF	16	9.6625	4.6003	1.1501	3.8000	18.700	.476
NRMSITHT	16	86.637	2.7517	.68792	79.900	91.300	.032
TRAGHTS	15	73.607	3.0068	.77634	65.600	78.500	.041
TRAGDPS	15	.72000	2.6450	.68293	-4.8000	5.3000	3.674
BITRGDI	16	14.281	.62099	.15525	13.200	15.400	.043

GLABHTS	16	77.575	2.8662	.71656	71.500	83.000	.037
GLABDPS	16	10.362	2.7522	.68805	4.6000	15.000	.266
EYELPHTS	16	75.737	2.9624	.74060	68.700	81.100	.039
EYELPDPS	16	8.8812	2.7569	.68922	2.6000	13.400	.310
EYELPWDG	16	3.2000	.24495	.61237 -1	2.9000	3.7000	.077
C7HTS	16	62.931	2.8691	.71727	55.500	68.200	.046
C7DPS	16	-8.9062	2.3256	.58141	-12.100	-3.2000	-.261
SSTRNHTS	16	55.950	2.6868	.67169	49.000	59.500	.048
SSTRNDPS	16	4.9875	2.2444	.56109	2.2000	10.100	.450
SHLDRHTS	16	56.231	2.9524	.73811	49.700	62.500	.053
SHLDRDPS	16	-4.1875	2.4221	.60552	-7.3000	.60000	-.578
SHLDRBR	16	38.419	1.3437	.33593	36.300	40.300	.035
ILCSPHTS	16	19.556	1.9880	.49699	17.400	26.000	.102
ILCSPDPS	16	12.125	1.2704	.31761	9.8000	14.200	.105
BISPNBR	16	25.069	2.1549	.53873	22.300	29.800	.086
TRCHHTS	16	8.4125	1.7154	.42884	7.0000	14.000	.204
TRCHDPS	16	10.350	1.8272	.45680	7.7000	13.400	.177
BITRCHDI	16	33.025	1.9095	.47736	29.400	36.000	.058
HIPBRSIT	16	36.019	1.6690	.41725	33.200	38.600	.046
ORBHTT	15	.26667	.73062	.18865	-1.2000	1.3000	2.740
ORBDPT	15	8.2800	1.1497	.29684	7.2000	10.800	.139
TRAGHTC7	15	10.380	1.5143	.39099	7.9000	13.300	.146
TRAGDPC7	15	9.5000	1.5232	.39328	7.1000	11.300	.160
GLABHTT	15	4.2467	.96870	.25012	2.5000	5.9000	.228
GLABDPT	15	9.9000	1.1452	.29568	8.9000	12.600	.116
EYELPHTT	15	2.4067	.67662	.17470	.90000	3.8000	.281
EYELPDPT	15	8.4267	1.1354	.29317	7.4000	11.100	.135
ECTCNATT	15	2.2467	.61975	.16002	.80000	3.5000	.276
ECTCNDPT	15	7.4733	1.1461	.29592	6.4000	9.8000	.153
SHLDRSX	16	-4.1875	2.4221	.60552	-7.3000	.60000	-.578
SHLDRSY	16	16.500	1.5501	.38751	14.100	18.900	.094
SHLDRSZ	16	56.231	2.9524	.73811	49.700	62.500	.053
C7 SX	16	-8.9062	2.3256	.58141	-12.100	-3.2000	-.261
C7 SY	16	-2.1750	1.3389	.33473	-4.8000	-.10000	-.616
C7 SZ	16	62.931	2.8691	.71727	55.500	68.200	.046
SSTRNSX	16	4.9875	2.2444	.56109	2.2000	10.100	.450
SSTRNSY	16	-2.1000	1.2905	.32262	-4.6000	-.10000	-.615
SSTRNSZ	16	55.950	2.6868	.67169	49.000	59.500	.048
TRAG SX	15	.72000	2.6450	.68293	-4.8000	5.3000	3.674
TRAG SY	13	5.9231	1.2531	.34755	3.7000	7.9000	.212
TRAG SZ	15	73.607	3.0068	.77634	65.600	78.500	.041
ORBITSX	16	8.7437	2.7785	.69462	2.4000	13.400	.318
ORBITSY	16	1.0312	1.6304	.40761	-1.6000	3.7000	1.581
ORBITSZ	16	73.619	3.0879	.77197	65.900	79.100	.042
GLAB SX	16	10.362	2.7522	.68805	4.6000	15.000	.266
GLAB SY	16	-2.3312	1.5857	.39641	-4.9000	.60000	-.680
GLAB SZ	16	77.575	2.8662	.71656	71.500	83.000	.037
EYELPSX	16	8.8812	2.7569	.68922	2.6000	13.400	.310
EYELPSY	16	.89375	1.5533	.38832	-1.6000	3.6000	1.738
EYELPSZ	16	75.737	2.9624	.74060	68.700	81.100	.039
ECCANSX	16	7.9187	2.7086	.67714	1.8000	12.700	.342
ECCANSY	16	2.1937	1.5159	.37898	-.10000	4.7000	.691
ECCANSZ	16	75.575	3.0477	.76193	68.100	80.900	.040

APPENDIX C

RANGE OF MOTION, MUSCLE REFLEX TIME AND MUSCLE STRENGTH-DESCRIPTIVE STATISTICS

Summary descriptive statistics from the range of motion (from photogrammetry), sternomastoid muscle reflex time, and lateral flexor strength tests are contained in this appendix. These data are reported in the following order:

Table		
C.1	All Subjects Combined	
C.2	Subjects Grouped by Sex	--Females
C.3		--Males
C.4	Subjects Grouped by Sex and Age	--Females, 18-24 yrs
C.5		--Females, 35-44 yrs
C.6		--Females, 62-74 yrs
C.7		--Males, 18-24 yrs
C.8		--Males, 35-44 yrs
C.9		--Males, 62-74 yrs

The data tables are in the format produced by the University of Michigan Statistical Research Laboratory Michigan Interactive Data Analysis System (MIDAS). Each of the measurements is given a code name; the measurement name associated with the code names are identified below. Range of motion data are Euler angles (yaw, pitch are roll) in degrees, reflex times are in milliseconds and muscle strengths are in lbf.

CODE NAME	MEASUREMENT NAME
RANGE OF MOTION	
P2NEUTY	Photo 2--Neutral Head Position--Yaw
P2NEUTP	Photo 2--Neutral Head Position--Pitch
P2NEUTR	Photo 2--Neutral Head Position--Roll
P3EXTY	Photo 3--Extension--Yaw
P3EXTP	Photo 3--Extension--Pitch
P3EXTR	Photo 3--Extension--Roll
P4FLEXY	Photo 4--Flexion--Yaw
P4FLEXP	Photo 4--Flexion--Pitch
P4FLEXR	Photo 4--Flexion--Roll
P5RTROTY	Photo 5--Right Rotation--Yaw
P5RTROTP	Photo 5--Right Rotation--Pitch
P5RTROTR	Photo 5--Right Rotation--Roll
P6LTROTY	Photo 6--Left Rotation--Yaw
P6LTROTP	Photo 6--Left Rotation--Pitch
P6LTROTR	Photo 6--Left Rotation--Role
P7RLBNDY	Photo 7--Right Lateral Bend--Yaw
P7RLBNDP	Photo 7--Right Lateral Bend--Pitch
P7RLBNDR	Photo 7--Right Lateral Bend--Roll
P8LLBNDY	Photo 8--Left Lateral Bend--Yaw
P8LLBNDP	Photo 8--Left Lateral Bend--Pitch
P8LLBNDR	Photo 8--Left Lateral Bend--Roll
P9LROFLY	Photo 9--Left Rotation + Flexion--Yaw
P9LROFLP	Photo 9--Left Rotation + Flexion--Pitch
P9LROFLR	Photo 9--Left Rotation + Flexion--Roll
P10LROBY	Photo 10--Left Rotation + Left Lateral Bend--Yaw
P10LROBP	Photo 10--Left Rotation + Left Lateral Bend--Pitch
P10LROBR	Photo 10--Left Rotation + Left Lateral Bend--Roll
P11RROXY	Photo 11--Right Rotation + Extension--Yaw
P11RROXP	Photo 11--Right Rotation + Extension--Pitch
P11RROXR	Photo 11--Right Rotation + Extension--Roll
PSAGROM	Sagittal Range of Motion from Photogrammetry (P3EXTP + P4FLEXP)
PROTROM	Rotational Range of Motion from Photogrammetry (P5RTROTY + P6LTROTY)
PLATROM	Lateral Bend Range of Motion from Photogrammetry (P7RLBNDR + P8LLBNOR)
REFLEX TIME	
RFLXAVG	Reflex Time of Sternomastoid muscles (average of several trials)

CODE NAME	MEASUREMENT NAME
MUSCLE STRENGTH	
RTMUSTR1	Strength of Right Lateral Flexors--Trial 1
RTMUSTR2	Strength of Right Lateral Flexors--Trial 2
RTMUSTR3	Strength of Right Lateral Flexors--Trial 3
RTMUSAVG	Average Strength of Right Lateral Flexors (Avg of 3 Trials)
LTMUSTR1	Strength of Left Lateral Flexors--Trial 1
LTMUSTR2	Strength of Left Lateral Flexors--Trial 2
LTMUSTR3	Strength of Left Lateral Flexors--Trial 3
LTMUSAVG	Average Strength of Left Lateral Flexors (Avg of 3 Trials)
RLAVGSTR	Average Strength of Lateral Flexors (Avg of 3 Right and 3 Left Trials)

The following summary statistics are reported for each measurement:

COLUMN HEADING	STATISTIC
N	Number of Subjects in the Group
MEAN	Numerical Average
STD DEV	Standard Deviation
SE OF MEAN	Standard Error of Mean
MINIMUM	Smallest Observation
MAXIMUM	Largest Observation
COEFF VAR	Coefficient of Variation (Mean/Std Dev)
5TH %ILE	Fifth Percentile (Calculated)
50TH %ILE	Fiftieth Percentile (Calculated)
95TH %ILE	Ninety-fifth Percentile (Calculated)

Note: MIDAS specifies, as the percentile, the individual measurement which is closest to the requested percentile. For example, in a dataset of 96 observations, the 5th smallest is called the 5th percentile, the 48th in rank is the 50th percentile and the 91st is the 95th percentile. This approach can cause misleading errors when small subsets of the data are analyzed (ex.: for a group of 15 subjects, the minimum value is also called the 5th percentile). Therefore, the percentiles are not included in Tables C.4 through C.9.

Table C.1

RANGE OF MOTION, REFLEX TIME AND STRENGTH-ALL SUBJECTS COMBINED

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR	5TH %ILE	50TH %ILE	95TH %ILE
P2NEUTY	96	-.41667 -1	3.1056	.31696	-11.700	7.7000	-74.534	-4.800	-.100	5.200
P2NEUTP	96	-1.3146	4.0774	.41615	-12.000	7.5000	-3.102	-8.500	-1.200	5.200
P2NEUTR	95	-1.0989	1.6760	.17195	-4.9000	3.7000	-1.525	-4.100	-1.000	1.700
P3EXTY	64	.57187	6.1090	.76362	-17.600	20.000	10.682	-8.400	.100	11.200
P3EXTP	96	54.180	18.122	1.8496	17.300	102.00	.334	24.000	52.300	88.000
P3EXTR	47	-.78723	4.8074	.70123	-9.2000	11.500	-6.107	-8.800	-.100	6.000
P4FLEXY	90	1.9078	6.5613	.69162	-15.900	20.100	3.439	-9.200	1.600	11.400
P4FLEXP	95	-49.548	13.244	1.3588	-79.900	-12.800	-.267	-71.800	-49.800	-26.200
P4FLEXR	89	-4.4831	5.3314	.56513	-16.800	16.400	-1.189	-13.100	-4.800	4.100
P5RTROTY	96	67.466	10.249	1.0460	36.600	89.600	.152	49.900	67.300	82.800
P5RTROTP	96	-1.1208	5.2855	.53945	-14.200	11.900	-4.716	-9.500	-1.300	7.400
P5RTROTR	95	4.3484	4.9757	.51049	-6.2000	22.700	1.144	-3.200	3.900	12.400
P6LTROTY	96	-69.030	9.7455	.99464	-89.600	-47.800	-.141	-84.000	-69.600	-50.000
P6LTROTP	94	-2.1362	5.6133	.57897	-13.800	15.600	-2.628	-10.500	-2.700	7.900
P6LTROTR	95	-9.8326	5.7043	.58525	-24.600	-.20000	-.580	-21.200	-9.000	-2.500
P7RLBNDY	91	2.9516	7.2983	.76507	-21.000	19.900	2.473	-8.400	2.400	14.100
P7RLBNDP	92	1.8435	6.5141	.67914	-12.700	16.400	3.534	-11.100	2.000	12.700
P7RLBNDR	95	32.494	12.058	1.2371	6.2000	61.500	.371	13.100	32.000	56.200
P8LLBNDY	95	-6.0842	7.8058	.80086	-27.300	11.200	-1.283	-19.100	-5.500	7.200
P8LLBNDP	94	2.1989	7.1823	.74080	-18.400	19.400	3.266	-9.700	2.100	14.500
P8LLBNDR	96	-38.315	11.538	1.1776	-69.400	-12.500	-.301	-57.600	-37.600	-19.300
P9LROFLY	95	-67.211	9.9044	1.0162	-89.300	-43.700	-.147	-83.500	-67.500	-49.100
P9LROFLP	95	-24.641	7.4994	.76942	-39.300	-8.9000	-.304	-36.600	-24.500	-12.600
P9LROFLR	93	-14.092	7.0811	.73427	-32.500	5.7000	-.502	-26.300	-14.200	-3.400
P10LROBY	85	-68.060	9.4845	1.0287	-88.600	-47.800	-.139	-85.400	-67.600	-52.600
P10LROBP	85	7.8718	9.5403	1.0348	-13.400	35.200	1.212	-6.900	7.700	22.000
P10LROBR	79	-37.810	10.709	1.2048	-64.600	-16.600	-.283	-54.100	-37.800	-21.400
P11RROXY	95	64.514	11.575	1.1875	25.900	88.300	.179	44.300	64.900	81.400
P11RROXP	94	18.419	7.9613	.82114	1.3000	44.900	.432	6.200	17.500	32.600
P11RROXR	92	6.9913	8.2845	.86372	-13.700	26.600	1.185	-7.100	7.800	20.600
PSAGROM	95	103.74	27.248	2.7955	45.500	165.80	.263	60.300	100.400	152.000
PROTROM	96	136.50	18.126	1.8500	86.600	175.60	.133	102.600	138.400	162.000
PLATROM	95	70.956	22.244	2.2822	25.000	130.90	.313	35.600	67.900	111.600
RFLXAVG	94	50.194	11.862	1.2235	25.200	80.000	.236	29.300	50.700	70.300
RTMUSTR1	92	19.880	8.9392	.93197	6.0000	45.000	.450	7.000	19.000	35.000
RTMUSTR2	93	20.860	9.1135	.94503	6.0000	50.000	.437	7.000	20.000	36.000
RTMUSTR3	94	21.234	9.9108	1.0222	6.0000	55.000	.467	8.000	20.000	39.000
RTMUSAVG	94	20.619	9.2674	.95586	6.0000	50.000	.449	7.300	19.700	36.500
LTMUSTR1	92	20.978	9.9460	1.0369	7.0000	48.000	.474	7.000	20.000	36.000
LTMUSTR2	93	21.516	10.101	1.0474	6.0000	48.000	.469	7.000	20.000	37.000
LTMUSTR3	93	21.817	10.412	1.0797	7.0000	52.000	.477	8.000	20.000	40.000
LTMUSAVG	93	21.380	10.077	1.0450	6.5000	48.700	.471	7.300	20.300	37.000
RLAVGSTR	94	21.011	9.4952	.97935	6.8000	49.300	.452	7.500	19.800	36.300

Table C.2 RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX-FEMALES

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR	5TH %ILE	50TH %ILE	95TH %ILE
P2NEUTY	48	.72917 -1	2.7077	.39083	-5.1000	7.7000	37.135	-3.800	-.200	4.000
P2NEUTP	48	-.46667	4.1066	.59274	-12.000	7.5000	-8.800	-6.600	-.200	5.600
P2NEUTR	48	-1.3500	1.8439	.26615	-4.9000	3.7000	-1.366	-4.500	-1.100	.800
P3EXTY	32	.71875 -1	5.6469	.99825	-17.600	13.600	78.566	-11.000	.100	11.200
P3EXTP	48	53.646	16.489	2.3800	17.300	90.500	.307	26.100	53.900	84.000
P3EXTR	25	-1.4360	5.3508	1.0702	-9.2000	11.500	-3.726	-8.900	-1.700	7.300
P4FLEXY	46	1.0848	5.8096	.85659	-12.900	10.900	5.356	-9.200	1.000	9.500
P4FLEXP	48	-50.510	12.985	1.8742	-79.900	-23.700	-.257	-70.700	-53.000	-26.200
P4FLEXR	44	-4.9864	4.6625	.70291	-13.500	9.1000	-.935	-10.500	-5.600	3.400
P5RTROTY	48	68.483	9.3892	1.3552	45.300	85.100	.137	51.500	68.300	82.100
P5RTROTP	48	-.15833	5.2861	.76299	-9.5000	11.900	-33.386	-8.300	-.300	7.500
P5RTROTR	47	5.3681	5.3207	.77611	-6.2000	22.700	.991	-2.000	4.400	14.900
P6LTROTY	48	-70.779	8.5430	1.2331	-86.100	-52.700	-.121	-83.800	-71.400	-54.400
P6LTROTP	47	-1.9362	5.4849	.80005	-12.700	10.300	-2.833	-9.600	-2.300	7.900
P6LTROTR	47	-12.677	5.9446	.86712	-24.600	-2.1000	-.469	-22.300	-12.100	-4.600
P7RLBNDY	44	1.7273	6.7721	1.0209	-21.000	14.100	3.921	-8.400	.800	12.500
P7RLBNDP	45	2.4778	6.7162	1.0012	-11.700	16.400	2.711	-11.100	2.400	14.200
P7RLBNDR	48	31.725	11.410	1.6469	11.500	57.500	.360	15.000	29.800	53.400
P8LLBNDY	47	-5.9638	8.2647	1.2055	-27.300	9.5000	-1.386	-17.100	-5.500	7.300
P8LLBNDP	46	2.1652	7.9454	1.1715	-18.400	19.400	3.670	-10.200	2.200	15.200
P8LLBNDR	48	-40.317	10.397	1.5007	-66.900	-12.800	-.258	-57.600	-40.200	-26.100
P9LROFLY	47	-67.936	10.230	1.4922	-87.200	-45.600	-.151	-83.900	-68.700	-49.200
P9LROFLP	47	-25.332	7.3781	1.0762	-39.300	-11.700	-.291	-36.600	-25.400	-13.100
P9LROFLR	45	-16.489	7.2149	1.0755	-32.500	-.40000	-.438	-28.200	-15.600	-6.700
P10LROBY	42	-69.679	10.164	1.5684	-88.600	-47.800	-.146	-85.700	-70.000	-52.600
P10LROBP	42	5.8667	10.087	1.5565	-12.500	35.200	1.719	-11.500	4.200	22.000
P10LROBR	40	-40.277	10.030	1.5859	-64.600	-21.400	-.249	-60.700	-40.000	-26.300
P11RROXY	48	66.381	10.932	1.5779	39.700	88.300	.165	47.800	68.100	83.700
P11RROXP	47	18.964	7.8679	1.1477	3.7000	44.900	.415	9.300	18.400	32.600
P11RROXR	46	9.1978	7.1662	1.0566	-8.1000	26.600	.779	-2.700	8.900	20.600
PSAGROM	48	104.16	24.813	3.5815	58.400	152.80	.238	61.500	100.400	139.300
PROTROM	48	139.26	15.473	2.2334	104.50	164.30	.111	111.300	141.700	161.200
PLATROM	48	72.042	20.635	2.9785	25.900	124.40	.286	43.800	67.700	111.900
RFLXAVG	47	47.113	11.815	1.7234	25.200	70.700	.251	27.600	49.600	66.000
RTMUSTR1	48	15.208	5.9963	.86549	6.0000	28.000	.394	7.000	15.000	27.000
RTMUSTR2	47	16.085	6.1497	.89702	6.0000	28.000	.382	7.000	16.000	27.000
RTMUSTR3	48	16.083	6.7061	.96794	6.0000	32.000	.417	7.000	15.000	29.000
RTMUSAVG	48	15.706	6.1814	.89221	6.0000	29.000	.394	7.000	15.300	27.000
LTMUSTR1	46	15.761	7.0117	1.0338	7.0000	35.000	.445	7.000	14.000	27.000
LTMUSTR2	47	16.277	7.4708	1.0897	6.0000	37.000	.459	7.000	15.000	29.000
LTMUSTR3	47	16.404	7.3799	1.0765	7.0000	36.000	.450	7.000	16.000	32.000
LTMUSAVG	47	16.066	7.2461	1.0570	6.5000	36.000	.451	7.300	14.300	29.300
RLAVGSTR	48	15.979	6.5330	.94295	6.8000	32.200	.409	7.300	15.200	27.800

Table C.3 RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX-MALES

P2NEUTY	48	-.15625	3.4837	.50283	-11.700	6.2000	-22.296	-5.000	.300	5.300
P2NEUTP	48	-2.1625	3.9079	.56406	-10.700	6.6000	-1.807	-9.600	-2.100	3.400
P2NEUTR	47	-.84255	1.4605	.21303	-3.4000	2.2000	-1.733	-2.900	-.800	1.700
P3EXTY	32	1.0719	6.5909	1.1651	-10.600	20.000	6.149	-8.400	-.300	14.700
P3EXTP	48	54.715	19.782	2.8552	19.500	102.00	.362	23.800	51.700	88.000
P3EXTR	22	-.50000 -1	4.1026	.87467	-8.8000	6.0000	-82.052	-7.000	.500	5.600
P4FLEXY	44	2.7682	7.2319	1.0902	-15.900	20.100	2.612	-8.300	2.200	13.700
P4FLEXP	47	-48.566	13.572	1.9797	-79.400	-12.800	-.279	-73.600	-48.500	-31.100
P4FLEXR	45	-3.9911	5.9247	.88320	-16.800	16.400	-1.484	-13.300	-3.400	4.100
P5RTROTY	48	66.448	11.047	1.5945	36.600	89.600	.166	47.100	65.800	83.400
P5RTROTP	48	-2.0833	5.1607	.74488	-14.200	9.7000	-2.477	-11.900	-2.500	7.200
P5RTROTR	48	3.3500	4.4440	.64143	-4.5000	12.400	1.327	-3.200	2.800	11.500
P6LTROTY	48	-67.281	10.618	1.5326	-89.600	-47.800	-.158	-86.100	-67.800	-49.400
P6LTROTP	47	-2.3362	5.7912	.84473	-13.800	15.600	-2.479	-10.500	-3.400	6.300
P6LTROTR	48	-7.0479	3.8058	.54931	-15.400	-.20000	-.540	-13.500	-6.400	-2.100
P7RLBNDY	47	4.0979	7.6530	1.1163	-17.000	19.900	1.868	-6.900	3.300	18.700
P7RLBNDP	47	1.2362	6.3267	.92285	-12.700	14.700	5.118	-11.000	1.300	9.800
P7RLBNDR	47	33.279	12.762	1.8615	6.2000	61.500	.383	12.500	33.500	56.200
P8LLBNDY	48	-6.2021	7.4150	1.0703	-20.200	11.200	-1.196	-19.100	-7.100	4.700
P8LLBNDP	48	2.2312	6.4521	.93128	-10.700	15.100	2.892	-6.900	1.700	13.100
P8LLBNDR	48	-36.312	12.361	1.7842	-69.400	-12.500	-.340	-57.100	-34.100	-18.000
P9LROFLY	48	-66.500	9.6294	1.3899	-89.300	-43.700	-.145	-78.800	-67.200	-49.100
P9LROFLP	48	-23.965	7.6327	1.1017	-37.200	-8.9000	-.319	-36.100	-24.400	-10.900
P9LROFLR	48	-11.846	6.2261	.89865	-22.300	5.7000	-.526	-21.500	-12.500	-2.800
P10LROBY	43	-66.479	8.5951	1.3107	-86.600	-48.800	-.129	-81.200	-65.800	-53.600
P10LROBP	43	9.8302	8.6462	1.3185	-13.400	34.800	.880	-2.000	9.800	21.800
P10LROBR	39	-35.279	10.916	1.7479	-56.000	-16.600	-.309	-53.500	-34.900	-18.200
P11RROXY	47	62.606	12.013	1.7523	25.900	86.700	.192	33.300	62.700	78.000
P11RROXP	47	17.874	8.1013	1.1817	1.3000	42.000	.453	5.100	17.200	32.300
P11RROXR	46	4.7848	8.8024	1.2978	-13.700	25.100	1.840	-10.500	4.300	16.900
PSAGROM	47	103.31	29.794	4.3459	45.500	165.80	.288	59.400	99.500	154.400
PROTROM	48	133.73	20.225	2.9193	86.600	175.60	.151	99.300	133.900	163.700
PLATROM	47	69.847	23.949	3.4934	25.000	130.90	.343	33.400	71.700	108.600
RFLXAVG	47	53.274	11.203	1.6341	29.700	80.000	.210	34.300	52.700	70.700
RTMUSTR1	44	24.977	8.8803	1.3388	7.0000	45.000	.356	11.000	25.000	42.000
RTMUSTR2	46	25.739	9.1103	1.3432	7.0000	50.000	.354	11.000	26.000	38.000
RTMUSTR3	46	26.609	9.9095	1.4611	7.0000	55.000	.372	11.000	26.000	42.000
RTMUSAVG	46	25.746	9.2183	1.3592	7.0000	50.000	.358	11.000	26.000	39.700
LTMUSTR1	46	26.196	9.7585	1.4388	8.0000	48.000	.373	11.000	25.000	45.000
LTMUSTR2	46	26.870	9.6738	1.4263	10.000	48.000	.360	11.000	27.000	45.000
LTMUSTR3	46	27.348	10.203	1.5043	10.000	52.000	.373	12.000	27.000	48.000
LTMUSAVG	46	26.809	9.7118	1.4319	9.7000	48.700	.362	10.700	26.700	46.700
RLAVGSTR	46	26.261	9.3043	1.3718	8.3000	49.300	.354	11.000	26.000	43.200

Table C.4 RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX & AGE-FEMALES, 18-24

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
P2NEUTY	16	.40000	3.4000	.8500C	-5.1000	7.7000	8.50C
P2NEUTP	16	.18750 -1	5.0167	1.2542	-12.000	7.5000	267.556
P2NEUTR	16	-1.0062	1.7498	.43746	-4.3000	2.4000	-1.739
P3EXTY	9	.50000	8.4918	2.8306	-17.600	13.600	16.984
P3EXTP	16	64.737	14.963	3.7409	44.700	90.500	.231
P3EXTR	5	-.58000	6.4341	2.8774	-8.8000	7.3000	-11.093
P4FLEXY	15	.78000	5.4342	1.4031	-12.900	10.900	6.967
P4FLEXP	16	-59.312	9.2143	2.3036	-79.900	-45.800	-.155
P4FLEXR	14	-3.7857	6.3952	1.7092	-13.500	9.1000	-1.689
P5RTROTY	16	74.106	6.6746	1.6686	58.000	82.100	.090
P5RTROTP	16	-.46250	4.8194	1.2048	-8.5000	6.6000	-10.420
P5RTROTR	15	5.1400	3.5962	.92853	-.50000	12.200	.700
P6LTROTY	16	-76.487	6.2253	1.5563	-86.100	-65.400	-.081
P6LTROTP	16	-1.8687	5.9221	1.4805	-12.700	7.9000	-3.169
P6LTROTR	16	-9.1375	4.6517	1.1629	-20.100	-2.1000	-.509
P7RLBNDY	14	1.0643	6.1456	1.6425	-10.400	7.2000	5.774
P7RLBNDP	15	-.83333	5.5770	1.4400	-11.500	6.9000	-6.692
P7RLBNDR	16	40.406	11.353	2.8382	25.800	57.500	.281
P8LLBNDY	16	-5.1062	8.1490	2.0372	-27.300	9.5000	-1.596
P8LLBNDP	15	.88000	8.1207	2.0968	-18.400	15.400	9.228
P8LLBNDR	16	-45.587	10.538	2.6345	-66.900	-32.800	-.231
P9LROFLY	15	-74.660	9.3359	2.4105	-87.200	-52.000	-.125
P9LROFLP	15	-30.267	4.4566	1.1507	-36.600	-22.600	-.147
P9LROFLR	14	-13.557	6.7218	1.7965	-26.300	-.40000	-.496
P10LROBY	14	-73.693	9.0145	2.4092	-85.400	-52.600	-.122
P10LROBP	14	4.0429	10.552	2.8201	-12.500	22.000	2.610
P10LROBR	14	-39.993	9.1011	2.4324	-52.300	-22.800	-.228
P11RROXY	16	70.144	6.9988	1.7497	53.300	81.400	.100
P11RROXP	15	22.047	9.6122	2.4819	9.3000	44.900	.436
P11RROXR	15	7.3467	6.0545	1.5633	-8.1000	14.700	.824
PSAGROM	16	124.05	17.168	4.2921	93.800	152.80	.138
PROTROM	16	150.59	8.3944	2.0986	138.40	164.30	.056
PLATROM	16	85.994	21.263	5.3156	59.300	124.40	.247
RFLXAVG	16	45.144	9.9505	2.4876	28.300	56.400	.220
RTMUSTR1	16	17.938	5.6624	1.4156	9.0000	28.000	.316
RTMUSTR2	16	18.188	6.3793	1.5948	8.0000	28.000	.351
RTMUSTR3	16	19.000	7.4565	1.8641	7.0000	32.000	.392
RTMUSAVG	16	18.319	6.3180	1.5795	8.0000	29.000	.345
LTMUSTR1	16	18.875	6.9845	1.7461	8.0000	35.000	.370
LTMUSTR2	16	19.438	7.1737	1.7934	8.0000	35.000	.369
LTMUSTR3	16	19.563	7.5008	1.8752	7.0000	33.000	.383
LTMUSAVG	16	19.262	7.1581	1.7895	7.7000	34.300	.372
RLAVGSTR	16	18.819	6.5381	1.6345	7.8000	31.700	.347

Table C.5 RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX & AGE-FEMALES, 35-44

P2NEUTY	16	.87500 -1	2.3346	.58366	-3.6000	4.9000	26.681
P2NEUTP	16	-1.8437	3.4232	.85581	-8.5000	4.0000	-1.857
P2NEUTR	16	-1.1312	2.0172	.50429	-4.8000	3.7000	-1.783
P3EXTY	10	.55000	5.7593	1.8212	-11.000	11.200	10.471
P3EXTP	16	52.662	13.498	3.3745	33.900	80.000	.256
P3EXTR	7	-.34286	4.6270	1.7489	-8.9000	4.4000	-13.496
P4FLEXY	15	2.6333	5.1148	1.3206	-6.6000	9.6000	1.942
P4FLEXP	16	-51.475	10.269	2.5674	-70.700	-34.800	-.200
P4FLEXR	14	-5.4000	3.8789	1.0367	-10.800	3.4000	-.718
P5RTROTY	16	71.625	7.2881	1.8220	62.700	85.100	.102
P5RTROTP	16	-.51875	5.9079	1.4770	-9.5000	11.900	-11.389
P5RTROTR	16	4.0750	7.3351	1.8338	-6.2000	22.700	1.800
P6LTROTY	16	-71.981	6.2125	1.5531	-81.600	-64.200	-.086
P6LTROTP	15	-3.6867	4.6528	1.2013	-9.6000	6.7000	-1.262
P6LTROTR	15	-12.947	5.5343	1.4289	-24.600	-5.1000	-.427
P7RLBNDY	15	1.2933	8.6388	2.2305	-21.000	14.100	6.680
P7RLBNDP	15	2.6333	7.3677	1.9023	-11.700	16.400	2.798
P7RLBNDR	16	31.637	8.3975	2.0994	17.400	50.200	.265
P8LLBNDY	15	-3.7800	8.1504	2.1044	-16.400	8.7000	-2.156
P8LLBNDP	15	3.1733	8.6433	2.2317	-10.200	19.400	2.724
P8LLBNDR	16	-42.219	8.9035	2.2259	-57.600	-26.400	-.211
P9LROFLY	16	-70.081	7.0216	1.7554	-83.900	-59.700	-.100
P9LROFLP	16	-25.500	8.3929	2.0982	-39.300	-11.700	-.329
P9LROFLR	15	-17.360	6.7441	1.7413	-31.900	-6.2000	-.388
P10LROBY	13	-73.515	9.1165	2.5284	-88.600	-61.400	-.124
P10LROBP	13	6.9000	12.816	3.5544	-6.9000	35.200	1.857
P10LROBR	11	-45.391	13.266	3.9997	-64.600	-21.400	-.292
P11RROXY	16	72.106	9.3001	2.3250	56.900	88.300	.129
P11RROXP	16	17.744	6.6372	1.6593	7.8000	32.600	.374
P11RROXP	15	10.120	9.1997	2.3754	-3.4000	26.600	.909
PSAGROM	16	104.14	20.176	5.0439	78.300	136.70	.194
PROTROM	16	143.61	10.375	2.5939	128.00	162.00	.072
PLATROM	16	73.856	15.188	3.7971	43.800	105.90	.206
RFLXAVG	16	43.575	12.685	3.1713	25.200	65.200	.291
RTMUSTR1	16	16.250	6.0608	1.5152	7.0000	28.000	.373
RTMUSTR2	16	17.125	5.6199	1.4050	7.0000	28.000	.328
RTMUSTR3	16	17.000	5.8424	1.4606	8.0000	29.000	.344
RTMUSAVG	16	16.794	5.7442	1.4360	7.3000	28.300	.342
LTMUSTR1	16	16.813	7.2316	1.8079	7.0000	35.000	.430
LTMUSTR2	16	17.938	7.6982	1.9246	7.0000	37.000	.429
LTMUSTR3	16	18.125	7.3564	1.8391	8.0000	36.000	.406
LTMUSAVG	16	17.619	7.3767	1.8442	7.3000	36.000	.419
RLAVGSTR	16	17.306	6.3705	1.5926	7.3000	32.200	.368

Table C.6 RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX & AGE-FEMALES, 62-74

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
P2NEUTY	16	-.26875	2.3924	.59810	-3.8000	3.2000	-8.902
P2NEUTP	16	.42500	3.5825	.89561	-4.6000	5.2000	8.429
P2NEUTR	16	-1.9125	1.7343	.43358	-4.9000	.40000	-.907
P3EXTY	13	-.59231	2.9361	.81433	-6.8000	2.7000	-4.957
P3EXTP	16	43.537	14.303	3.5757	17.300	64.000	.329
P3EXTR	13	-2.3538	5.5538	1.5403	-9.2000	11.500	-2.359
P4FLEXY	16	-.81250 -1	6.7332	1.6833	-10.700	9.5000	-82.870
P4FLEXP	16	-40.744	12.352	3.0881	-63.500	-23.700	-.303
P4FLEXR	16	-5.6750	3.4385	.85963	-10.500	.30000	-.606
P5RTROTY	16	59.719	7.2365	1.8091	45.300	70.800	.121
P5RTROTP	16	.50625	5.3589	1.3397	-7.3000	11.400	10.586
P5RTROTR	16	6.8750	4.0849	1.0212	1.8000	14.900	.594
P6LTROTY	16	-63.869	8.0059	2.0015	-80.000	-52.700	-.125
P6LTROTP	16	-.36250	5.5919	1.3980	-7.9000	10.300	-15.426
P6LTROTR	16	-15.962	5.7617	1.4404	-24.100	-6.1000	-.361
P7RLBNDY	15	2.7800	5.4159	1.3984	-3.2000	12.500	1.948
P7RLBNDP	15	5.6333	5.8256	1.5042	-4.9000	15.900	1.034
P7RLBNDR	16	23.131	7.0250	1.7562	11.500	33.500	.304
P8LLBNDY	16	-8.8687	8.1551	2.0388	-24.900	7.2000	-.920
P8LLBNDP	16	2.4250	7.4412	1.8603	-13.400	14.500	3.069
P8LLBNDR	16	-33.144	7.7466	1.9366	-43.300	-12.800	-.234
P9LROFLY	16	-59.487	8.0013	2.0003	-69.800	-45.600	-.135
P9LROFLP	16	-20.537	5.3907	1.3477	-32.800	-12.600	-.262
P9LROFLR	16	-18.237	7.6839	1.9210	-32.500	-7.1000	-.421
P10LROBY	15	-62.607	8.5150	2.1986	-74.500	-47.800	-.136
P10LROBP	15	6.6733	6.9862	1.8038	-4.6000	20.600	1.047
P10LROBR	15	-36.793	6.6351	1.7132	-52.300	-26.300	-.180
P11RROXY	16	56.894	9.6384	2.4096	39.700	78.000	.169
P11RROXP	16	17.294	6.7444	1.6861	3.7000	30.400	.390
P11RROXR	16	10.069	5.9809	1.4952	-2.7000	21.700	.594
PSAGROM	16	84.281	19.594	4.8984	58.400	119.00	.232
PROTROM	16	123.59	12.365	3.0912	104.50	147.30	.100
PLATROM	16	56.275	13.234	3.3086	25.900	76.800	.235
RFLXAVG	15	52.987	11.157	2.8807	31.500	70.700	.211
RTMUSTR1	16	11.438	4.4267	1.1067	6.0000	18.000	.387
RTMUSTR2	15	12.733	5.3381	1.3783	6.0000	20.000	.419
RTMUSTR3	16	12.250	5.0531	1.2633	6.0000	23.000	.412
RTMUSAVG	16	12.006	4.8648	1.2162	6.0000	20.000	.405
LTMUSTR1	14	11.000	3.9807	1.0639	7.0000	20.000	.362
LTMUSTR2	15	11.133	4.6731	1.2066	6.0000	23.000	.420
LTMUSTR3	15	11.200	4.1092	1.0610	7.0000	21.000	.367
LTMUSAVG	15	11.000	4.1700	1.0767	6.5000	21.300	.379
RLAVGSTR	16	11.812	4.6261	1.1565	6.8000	20.000	.392

Table C.7

RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX & AGE-MALES, 18-24

P2NEUTY	17	-.54118	2.7212	.65999	-5.9000	3.5000	-5.028
P2NEUTP	17	-1.6529	3.8550	.93499	-7.5000	6.6000	-2.332
P2NEUTR	17	-.50000	1.6298	.39528	-2.8000	2.2000	-3.260
P3EXTY	5	-.54000	3.8371	1.7160	-5.9000	3.0000	-7.106
P3EXTP	17	72.824	18.212	4.4170	38.000	102.00	.250
P3EXTR	3	-2.2667	5.0797	2.9328	-7.0000	3.1000	-2.241
P4FLEXY	14	3.3429	5.4671	1.4611	-5.0000	13.700	1.635
P4FLEXP	17	-56.176	11.614	2.8167	-79.400	-37.800	-.207
P4FLEXR	15	-3.4000	4.0041	1.0339	-13.300	1.8000	-1.178
P5RTROTY	17	73.212	9.3667	2.2718	54.200	89.600	.128
P5RTROTP	17	-2.3647	6.8831	1.6694	-14.200	9.7000	-2.911
P5RTROTR	17	4.1706	4.5887	1.1129	-1.3000	12.400	1.100
P6LTROTY	17	-76.235	7.2365	1.7551	-89.600	-61.800	-.095
P6LTROTP	17	-3.1588	6.0391	1.4647	-13.800	6.0000	-1.912
P6LTROTR	17	-6.3706	4.5623	1.1065	-15.400	-.20000	-.716
P7RLBNDY	16	1.2688	8.3780	2.0945	-17.000	14.000	6.603
P7RLBNDP	16	.28125	6.8195	1.7049	-12.100	9.4000	24.247
P7RLBNDR	17	41.694	12.576	3.0502	17.100	61.500	.302
P8LLBNDY	17	-4.3118	7.1602	1.7366	-12.700	11.200	-1.661
P8LLBNDP	17	3.4118	7.3652	1.7863	-10.700	15.100	2.159
P8LLBNDR	17	-44.612	11.344	2.7513	-69.400	-27.000	-.254
P9LROFLY	17	-73.224	7.4542	1.8079	-89.300	-55.600	-.102
P9LROFLP	17	-26.741	5.8860	1.4276	-36.600	-16.700	-.220
P9LROFLR	17	-9.6471	7.1840	1.7424	-21.500	5.7000	-.745
P10LROBY	15	-74.460	6.5571	1.6930	-86.600	-64.900	-.088
P10LROBP	15	9.7600	10.405	2.6866	-3.4000	34.800	1.066
P10LROBR	11	-41.409	12.167	3.6684	-56.000	-22.700	-.294
P11RROXY	16	68.700	9.8306	2.4577	53.800	86.700	.143
P11RROXP	16	17.387	10.966	2.7414	1.3000	42.000	.631
P11RROXR	16	4.9000	8.1376	2.0344	-11.700	20.900	1.661
PSAGROM	17	129.00	23.517	5.7038	80.600	165.80	.182
PROTROM	17	149.45	13.767	3.3390	123.30	175.60	.092
PLATROM	17	86.306	22.206	5.3857	44.300	130.90	.257
RFLXAVG	17	48.888	6.2699	1.5207	37.000	59.300	.128
RTMUSTR1	17	26.647	4.9110	1.1911	17.000	35.000	.184
RTMUSTR2	17	26.882	5.8404	1.4165	16.000	38.000	.217
RTMUSTR3	17	27.647	5.9155	1.4347	17.000	40.000	.214
RTMUSAVG	17	27.071	5.1089	1.2391	18.000	35.700	.189
LTMUSTR1	17	27.882	6.5277	1.5832	16.000	36.000	.234
LTMUSTR2	17	29.706	6.5647	1.5922	18.000	40.000	.221
LTMUSTR3	17	29.059	7.8380	1.9010	17.000	40.000	.270
LTMUSAVG	17	28.882	6.6458	1.6118	19.000	37.000	.230
RLAVGSTR	17	27.965	5.6359	1.3669	19.300	36.300	.202

Table C.8

RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX & AGE-MALES, 35-44

VARIABLE	N	MEAN	STD DEV	SE OF MEAN	MINIMUM	MAXIMUM	COEFF VAR
P2NEUTY	15	.10667	2.9190	.75369	-4.3000	5.3000	27.366
P2NEUTP	15	-2.0600	4.0201	1.0380	-10.700	3.4000	-1.952
P2NEUTR	14	-.75000	1.1601	.31004	-2.3000	1.1000	-1.547
P3EXTY	11	3.0545	7.6004	2.2916	-6.2000	20.000	2.488
P3EXTP	15	52.227	8.6712	2.2389	39.300	70.000	.166
P3EXTR	7	-.64286	4.0228	1.5205	-8.8000	3.7000	-6.258
P4FLEXY	14	2.3500	8.3669	2.2362	-13.500	16.700	3.560
P4FLEXP	14	-50.543	12.725	3.4008	-73.600	-31.400	-.252
P4FLEXR	14	-2.9786	7.4850	2.0004	-13.100	16.400	-2.513
P5RTROTY	15	68.507	8.3190	2.1480	56.900	83.400	.121
P5RTROTP	15	-2.5400	3.7889	.97828	-7.7000	7.2000	-1.492
P5RTROTR	15	3.2933	4.8120	1.2424	-4.5000	10.200	1.461
P6LTROTY	15	-68.613	5.9011	1.5237	-83.700	-57.900	-.086
P6LTROTP	15	-2.9200	5.1714	1.3352	-10.500	9.6000	-1.771
P6LTROTR	15	-7.7200	2.7251	.70361	-11.700	-3.0000	-.353
P7RLBNDY	15	6.8733	7.3133	1.8883	-3.3000	19.900	1.064
P7RLBNDP	15	-.35333	5.6799	1.4665	-12.700	7.9000	-16.075
P7RLBNDR	15	34.827	7.7006	1.9883	17.300	48.600	.221
P8LLBNDY	15	-8.2667	6.4821	1.6737	-20.200	.50000	-.784
P8LLBNDP	15	.16000	5.8926	1.5215	-6.9000	13.700	36.829
P8LLBNDR	15	-38.167	9.6473	2.4909	-60.000	-22.000	-.253
P9LROFLY	15	-68.407	5.5647	1.4368	-78.800	-59.700	-.081
P9LROFLP	15	-24.340	8.4223	2.1746	-35.400	-10.200	-.346
P9LROFLR	15	-13.633	6.0123	1.5524	-22.300	-3.4000	-.441
P10LROBY	15	-65.733	4.2079	1.0865	-72.600	-58.000	-.064
P10LROBP	15	9.3400	8.3270	2.1500	-13.400	20.900	.892
P10LROBR	15	-36.993	9.8156	2.5344	-53.500	-21.200	-.265
P11RROXY	15	64.353	7.7411	1.9987	51.200	78.000	.120
P11RROXP	15	19.067	6.8582	1.7708	11.400	35.800	.360
P11RROXR	15	4.4800	8.8505	2.2852	-13.700	16.900	1.976
PSAGROM	14	102.69	19.443	5.1963	73.500	129.20	.189
PROTROM	15	137.12	12.668	3.2708	116.10	165.40	.092
PLATROM	15	72.993	15.711	4.0565	49.300	108.60	.215
RFLXAVG	14	52.814	9.1007	2.4323	33.300	68.000	.172
RTMUSTR1	13	30.154	10.558	2.9283	12.000	45.000	.350
RTMUSTR2	14	31.786	9.4802	2.5337	12.000	50.000	.298
RTMUSTR3	14	33.500	10.953	2.9272	11.000	55.000	.327
RTMUSAVG	14	31.971	10.036	2.6823	11.700	50.000	.314
LTMUSTR1	14	32.286	10.644	2.8448	11.000	48.000	.330
LTMUSTR2	14	31.786	10.772	2.8788	10.000	48.000	.339
LTMUSTR3	14	33.071	11.262	3.0100	11.000	52.000	.341
LTMUSAVG	14	32.393	10.712	2.8630	10.700	48.700	.331
RLAVGSTR	14	32.129	10.231	2.7343	11.200	49.300	.318

Table C.9 RANGE OF MOTION, REFLEX TIME AND STRENGTH-BY SEX & AGE-MALES, 62-74

P2NEUTY	16	.62500	-2 4.6808	1.1702	-11.700	6.2000	748.929
P2NEUTP	16	-2.8000	4.0221	1.0C55	-10.600	2.6000	-1.436
P2NEUTR	16	-1.2875	1.4796	.36990	-3.4000	1.7000	-1.149
P3EXTY	16	.21250	6.5423	1.6356	-10.600	14.700	30.787
P3EXTP	16	37.806	10.925	2.7313	19.500	55.300	.289
P3EXTR	12	.85000	4.0207	1.1607	-5.8000	6.0000	4.730
P4FLEXY	16	2.6312	7.9284	1.9821	-15.900	20.100	3.013
P4FLEXP	16	-38.750	10.423	2.6C56	-54.400	-12.800	-.269
P4FLEXR	16	-5.4312	5.9940	1.4985	-16.800	4.1000	-1.104
P5RTROTY	16	57.331	8.9143	2.2286	36.600	70.100	.155
P5RTROTP	16	-1.3562	4.3188	1.0797	-12.700	5.7000	-3.184
P5RTROTR	16	2.5312	4.0407	1.0102	-3.8000	11.500	1.596
P6LTROTY	16	-56.519	6.9783	1.7446	-67.800	-47.800	-.123
P6LTROTP	15	-.82000	6.1742	1.5942	-6.4000	15.600	-7.529
P6LTROTR	16	-7.1375	3.9076	.97689	-14.200	-2.6000	-.547
P7RLBNDY	16	4.3250	6.5730	1.6433	-9.8000	18.800	1.520
P7RLBNDP	16	3.6812	6.0215	1.5054	-6.4000	14.700	1.636
P7RLBNDR	15	22.193	8.6500	2.2334	6.2000	39.700	.390
P8LLBNDY	16	-6.2750	8.3700	2.0925	-19.600	6.8000	-1.334
P8LLBNDP	16	2.9187	5.8133	1.4533	-8.0000	11.300	1.992
P8LLBNDR	16	-25.756	7.3665	1.8416	-42.300	-12.500	-.286
P9LROFLY	16	-57.569	7.9004	1.9751	-72.700	-43.700	-.137
P9LROFLP	16	-20.662	7.6729	1.9182	-37.200	-8.9000	-.371
P9LROFLR	16	-12.506	4.8509	1.2127	-21.200	-2.8000	-.388
P10LROBY	13	-58.131	5.6507	1.5672	-65.700	-48.800	-.097
P10LROBP	13	10.477	7.3270	2.0322	-.40000	22.000	.699
P10LROBR	13	-28.115	6.9161	1.9182	-37.700	-16.600	-.246
P11RROXY	16	54.875	13.549	3.3872	25.900	74.400	.247
P11RROXP	16	17.244	5.9183	1.4796	5.1000	32.300	.343
P11RROXR	15	4.9667	9.9810	2.5771	-10.500	25.100	2.010
PSAGROM	16	76.556	17.113	4.2783	45.500	104.60	.224
PROTROM	16	113.85	14.724	3.6810	86.600	134.70	.129
PLATROM	15	48.047	15.015	3.8770	25.000	82.000	.313
RFLXAVG	16	58.337	14.893	3.7234	29.700	80.000	.255
RTMUSTR1	14	18.143	6.8932	1.8423	7.0000	34.000	.380
RTMUSTR2	15	18.800	7.3892	1.9C79	7.0000	31.000	.393
RTMUSTR3	15	19.000	7.3095	1.8873	7.0000	31.000	.385
RTMUSAVG	15	18.433	7.1831	1.8547	7.0000	32.000	.390
LTMUSTR1	15	18.600	7.0589	1.8226	8.0000	35.000	.380
LTMUSTR2	15	19.067	6.6812	1.7251	10.000	35.000	.350
LTMUSTR3	15	20.067	7.3140	1.8885	10.000	37.000	.364
LTMUSAVG	15	19.247	6.9615	1.7975	9.7000	35.700	.362
RLAVGSTR	15	18.853	6.9297	1.7893	8.3000	33.800	.368

APPENDIX D

PHOTOGRAMMETRY ILLUSTRATIONS

Figures D.1 through D.3 on the following pages illustrate the sequence of photographs for the twelve photogrammetry positions for the x, y, and z cameras respectively. The numbers show the order in which the points were digitized.

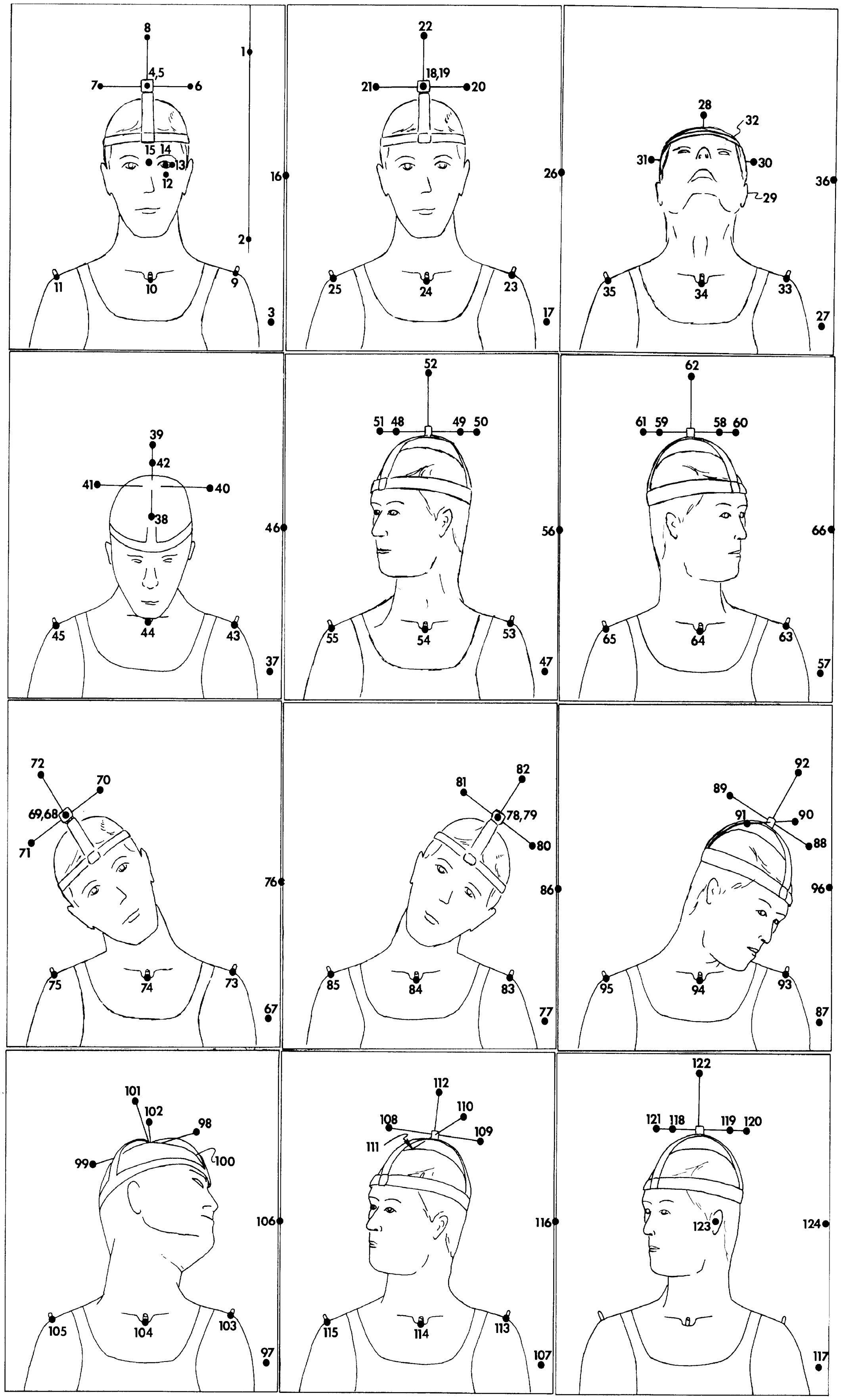


Figure D.1 Illustrations of x-camera photos and digitized points.

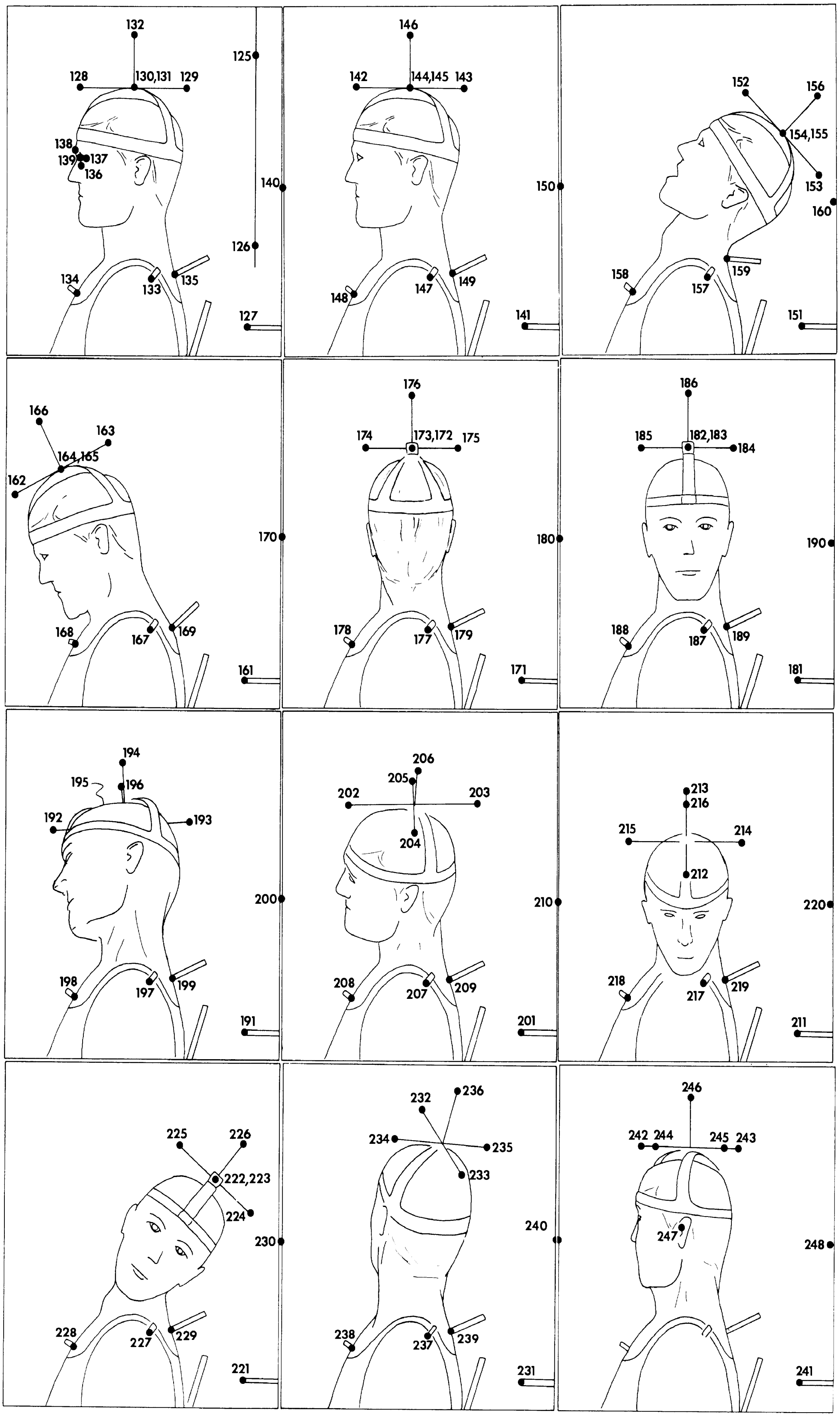


Figure D.2 Illustrations of y-camera photos and digitized points.

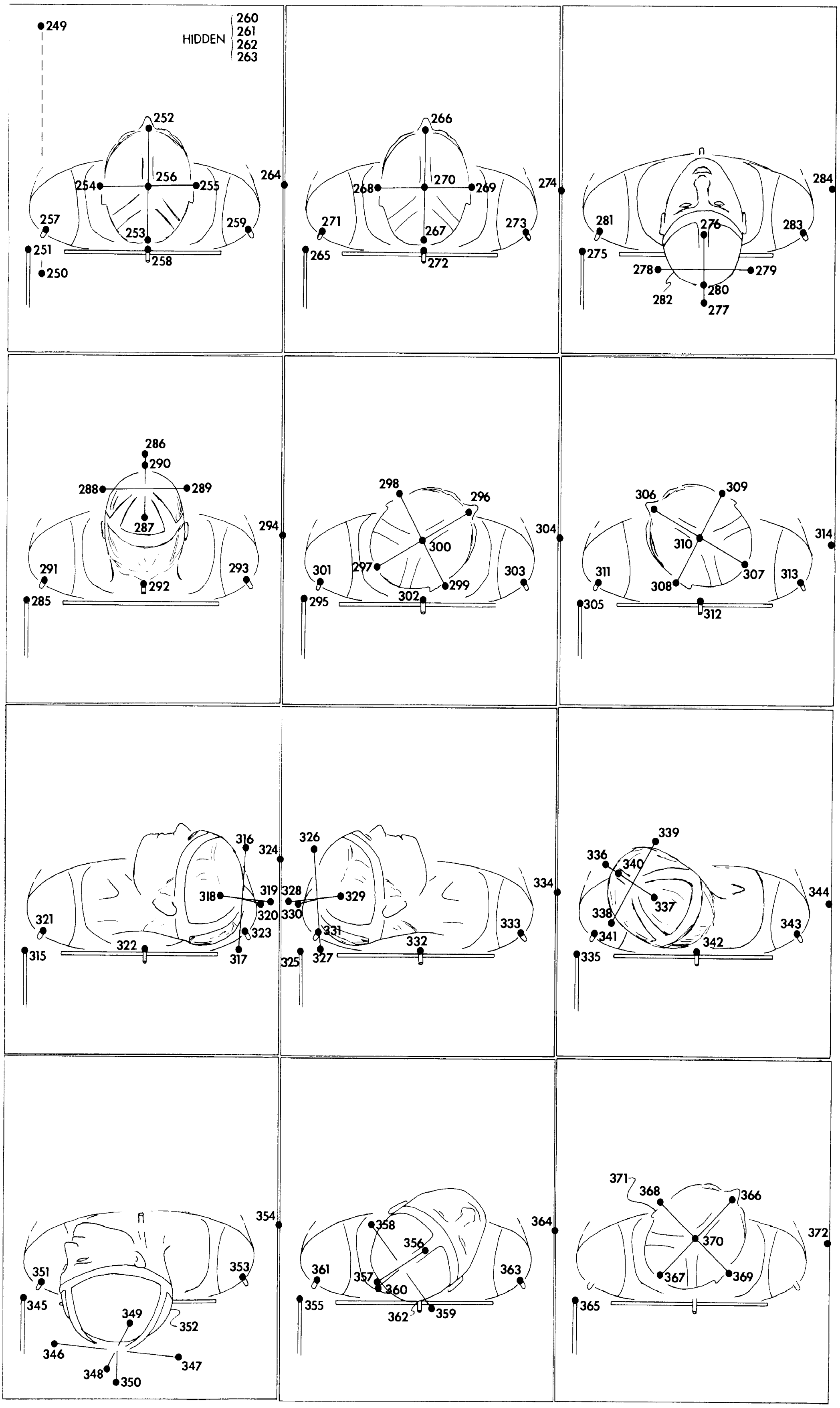


Figure D.3 Illustrations of z-camera photos and digitized points.

APPENDIX E

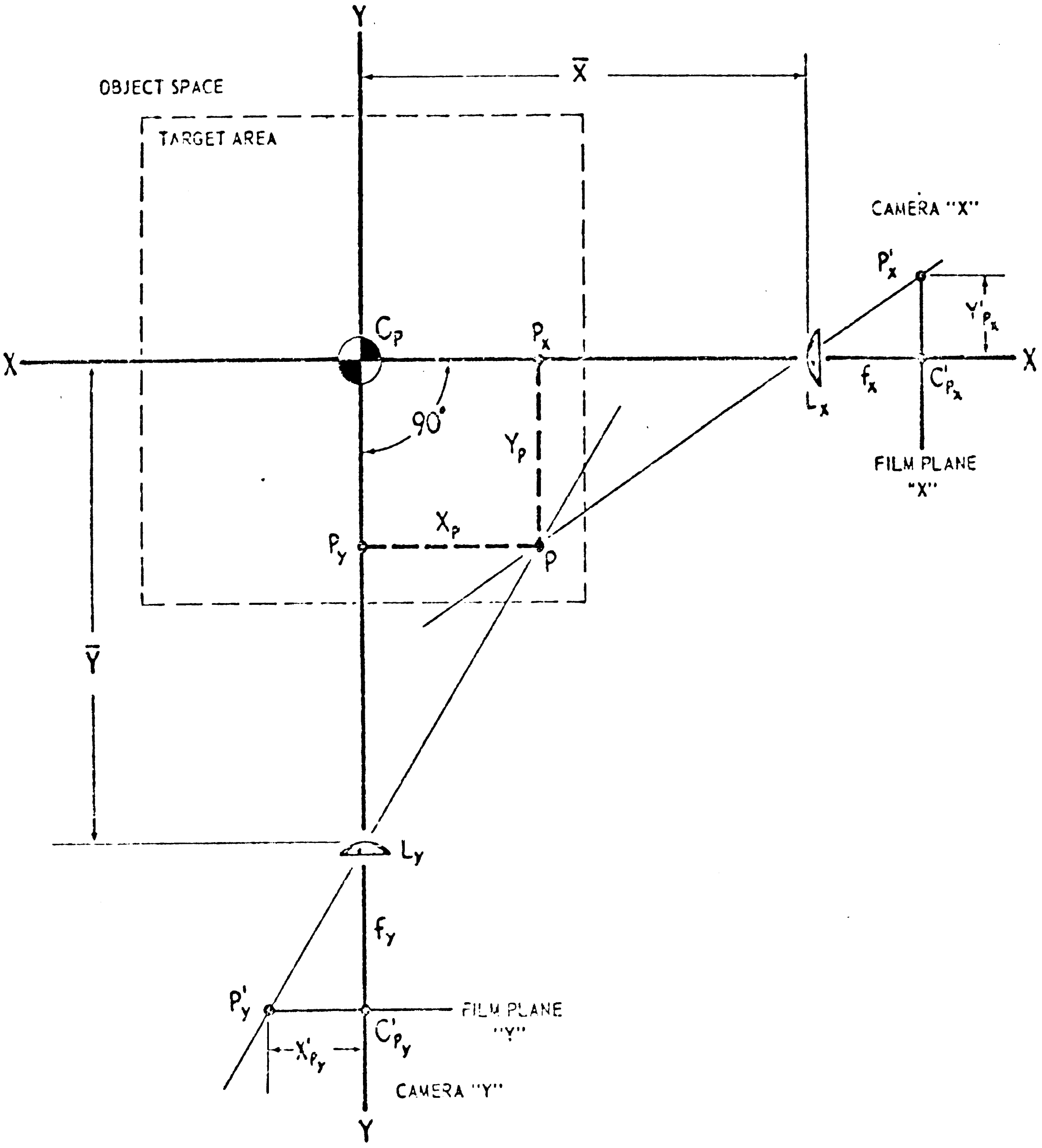
ANTHROPOMETRY AND RANGE OF MOTION FROM PHOTOGRAMMETRY

The technique of three-dimensional photogrammetry was used to make anthropometric measurements of specific anatomical landmarks on the head and the torso of seated subjects, and to determine the range of voluntary cervical motion. While, in theory, the x,y,z coordinates of any point in the field of view of two cameras whose optical axes intersect at 90 degrees may be computed, three cameras were used to ensure that all points of interest could be seen by at least two cameras. The point of intersection of the three camera optical axes is the "origin" of an inertial reference frame to which the x,y,z coordinates are related. The following pages are included in this report to explain the theoretical basis for calculating the actual coordinates of points in three-dimensional space, and the procedure for computing the range of motion from the change in orientation of a coordinate system attached to the head.

I. Theoretical Basis for Determining the Coordinates of a Point in Space

The following discussion of the theoretical basis of photogrammetry has been paraphrased from Chaffee (1961):

Figure E.1 shows how coordinates are established for two cameras, x and y. Line x-x is the optical axis of camera x and y-y is the optical axis of camera y. These axes intersect in a 90-degree angle at C_p forming the reference plane x-y. The film planes of each camera are perpendicular to their respective optical axes and lie at known distances, $(\overline{X} + f_x)$ and $(\overline{Y} + f_y)$ respectively, from C_p.



P = Point to be located
C_p = Photogrammetric center or reference point
X_p = Displacement of P in X direction
Y_p = Displacement of P in Y direction
$\bar{X}$ = Distance from C_p to X-camera lens, L_x
$\bar{Y}$ = Distance from C_p to Y-camera lens, L_y
f_x = Focal length (calibrated) of camera X
f_y = Focal length (calibrated) of camera Y

L_x = Lens of camera X
L_y = Lens of camera Y
X-X = X-camera optic axis
Y-Y = Y-camera optic axis
X'_{py} = X-direction displacement of point "P" image on Y-camera negative
Y'_{px} = Y-direction displacement of point "P" image on X-camera negative

Figure E.1 The orthogonal relationship of two photogrammetric cameras in the andrometric technique.

Point "P" in Figure E.1 represents a point for which we wish to determine the actual distances, x_p and y_p, from the reference point C_p. Light rays pass from "P" through both camera lenses L_x and L_y simultaneously to strike the exposed negatives at point P'_x in camera x and point P'_y in camera y.

Assuming that the image of the imaginary reference point C_p can be made to appear at C'_{px} on the film plane of camera x and at C'_{py} in camera y, it follows that P'_x, the image in camera x of point "P", appears to lie at a distance y'_{px} from C'_p on the film plane in camera x. Likewise if we assume that the image of C_p can also be made to appear in camera y at C'_{py}, then the image P'_y of point "P" appears to lie at x'_{py} distance from C'_{py} on the film plane in camera y. The apparent coordinates y'_{px} and x'_{py} are, then, visual analogs of the true but unknown coordinates, y_p and x_p, of point "P", with respect to C_p.

Because of this direct analogy in a carefully aligned orthogonal photographic arrangement between the object space location of "P" and the apparent location of the respective images of "P" on the films, y'_{px} in camera x is directly proportional to y_p, and x'_{py} in camera is directly proportional to x_p.

It should be realized, however, that these respective proportions depend on the true position of "P" in object space. The ratio of x'_{py} to x_p will vary as y_p varies, and the ratio of y'_{px} to y_p will change as x_p changes. In other words, the ratio of the film analog of the coordinate to the "true" coordinate, as seen in a given camera, will become numerically greater as the distance from the point "P" to that camera diminishes, and vice versa.

In terms of Figure E.1 this geometric relationship may be formally expressed in algebraic notation. For the case of the x camera, using the similar triangles L_x-C'_{px}-P'_x and L_x-P_x-P we have:

$$(1) \qquad \frac{y'_{px}}{f_x} = \frac{y_p}{(\bar{X} - x_p)}$$

$$(2) \qquad \frac{y'_{px}}{y_p} = \frac{f_x}{(\bar{X} - x_p)}$$

Where f_x is a constant equal to the calculated distance between the x camera lens, L_x, and the film plane; $(\bar{X}-x_p)$ represents the unknown distance between point "P" and the lens; and $\bar{X}$ represents the measured distance from C_p to the lens.

For the y camera an analogous equation for expressing the ratio of x'_{py} to x_p may be derived from the similar triangles L_y-C'_{py}-P_y and L_y-P_y-P:

$$(3) \qquad \frac{x'_{py}}{f_y} = \frac{x_p}{(\bar{Y} - y_p)}$$

$$(4) \qquad \frac{x'_{py}}{x_p} = \frac{f_y}{(\bar{Y} - y_p)}$$

Where f_y is a constant equal to the calculated distance between the lens L_y of the y camera and the film plane; $(\bar{Y}-y_p)$ represents the unknown distance between point "P" and the lens; and $\bar{Y}$ represents the measured distance from C_p to the lens. Equations (2) and (4) can be solved simultaneously and rewritten in the following form:

$$(5) \qquad x_p = x'_{py} \left(\frac{\bar{Y}_{fx} - \bar{X}\, y'_{px}}{f_x f_y - x'_{py}\, y'_{px}} \right)$$

Thus, the x_p coordinate of point "P" is seen to be a function of four constants: $\bar{X}$, $\bar{Y}$, f_x, f_y; and two variables: x'_{py} and y'_{px}. These two variables are the apparent or analog coordinates of point "P", from the image of C_p, as measured on the negatives obtained from the y and x cameras. Equation (5) is said to transform the analog coordinate, x'_{py}, into an estimate of the "true" coordinate, x_p.

In a similar manner the "true" y_p coordinate may be shown to be:

$$(6) \qquad y_p = y'_{px} \left(\frac{\bar{X}_{fy} - \bar{Y}\, x'_{py}}{f_x f_y - x'_{py}\, y'_{px}} \right)$$

We understand equation (6) to transform the analog coordinate, y'_{px}, into an estimate of the "true" coordinate, y_p.

The derivation of the z_p coordinate for a point "P" is similar but may be better conceptualized using Figure E.2, which is a three-dimensional representation of the two-camera geometry.

In this figure it may be seen that the apparent coordinates z'_{px} and z'_{py} are the analogs in cameras x and y, respectively, of the "true" vertical coordinate, z_p, of point "P", whose image in turn is represented as point P'_y in the y camera and P'_x in the x camera. The magnitudes of these analog coordinates are directly proportional to the actual coordinate, z_p, in object space. Again, these proportions or ratios vary with the "true" x_p and y_p position of point "P". As in the case of developing the equations for the x_p and y_p coordinates, we may express the "true" z_p coordinate in terms of the known parameters of the photogrammetric geometry and two measurements obtained from the negatives.

In Figure E.2 we see from similar triangles that:

$$(7) \qquad \frac{z'_{px}}{z_{px}} = \frac{f_x}{(\bar{X} - x_p)}$$

A similar equation for z_p may be developed from the analog coordinate, z'_{py}, as measured on the negative from the y camera. For convenience the estimate of z_p made from the x camera may be denoted as z_{px} and that made from the y camera as z_{py}. It can be shown that the equation for the latter is:

$$(8) \qquad z_{py} = z'_{py} \left(\frac{\bar{Y} f_x - \bar{X}\, y'_{px}}{f_x f_y - x'_{py}\, y'_{px}} \right)$$

which is the transformation from z'_{py} to z_{py}.

Figures E.3 through E.5 summarize the equations used to predict 3-dimensional coordinates using any two of the three cameras available.

For the experimental setup and cameras used in the present study the following values for f_y, f_x, f_z, $\bar{X}$, $\bar{Y}$, and $\bar{Z}$ have been measured or calculated.

Focal length, X-camera lens; f_x = 4.2058 in.

Focal length, Y-camera lens; f_y = 4.1411 in.

Focal length, Z-camera lens; f_z = 2.3159 in.

Distance, origin to X-camera lens; $\bar{X}$ = 140.19 in.

Distance, origin to Y-camera lens; $\bar{Y}$ = 133.11 in.

Distance, origin to Z-camera lens; $\bar{Z}$ = 84.73 in.

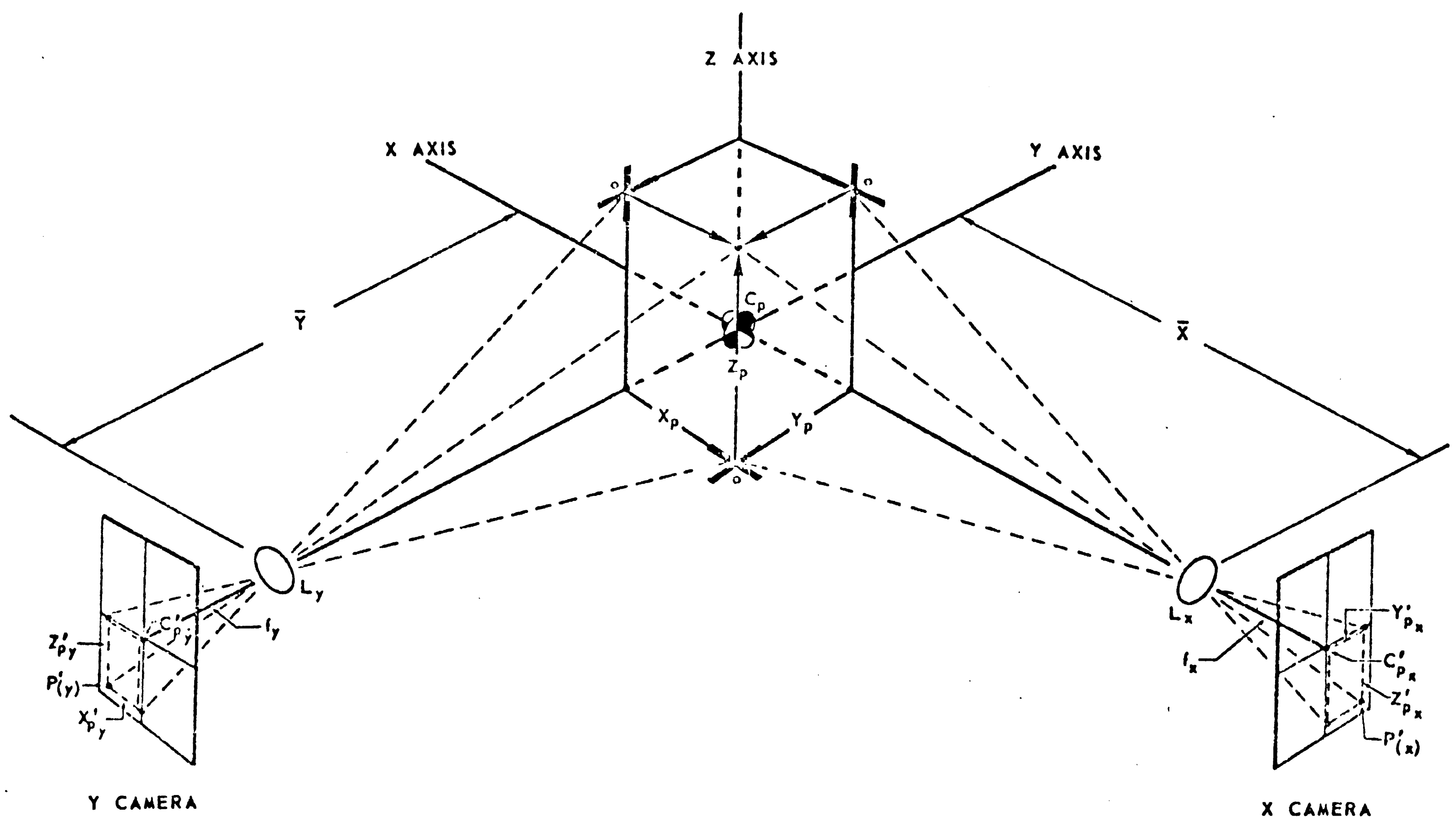
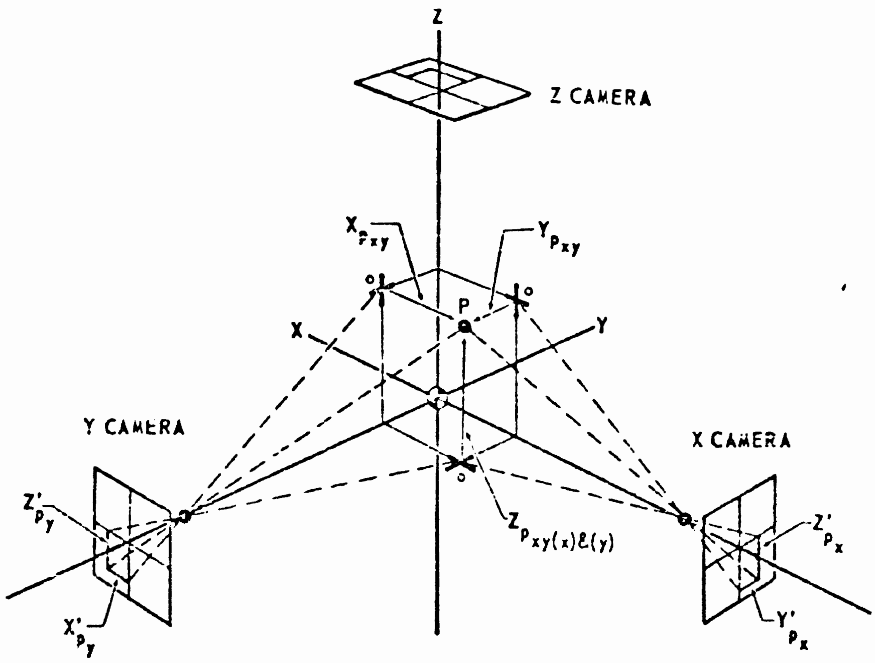


Figure E.2 Three dimensional representation of two-camera andrometric geometry.



TRANSFORMATION EQUATIONS

$$X_{p_{xy(y)}} = X'_{p_y}\left(\frac{\bar{Y}f_y - \bar{X}Y'_{p_x}}{f_x f_y - X'_{p_y}Y'_{p_x}}\right)$$

$$Y_{p_{xy(x)}} = Y'_{p_x}\left(\frac{\bar{X}f_y - \bar{Y}X'_{p_y}}{f_x f_y - X'_{p_y}Y'_{p_x}}\right)$$

$$Z_{p_{xy(x)}} = Z'_{p_x}\left(\frac{\bar{X}f_y - X'_{p_y}\bar{Y}}{f_x f_y - X'_{p_y}Y'_{p_x}}\right)$$

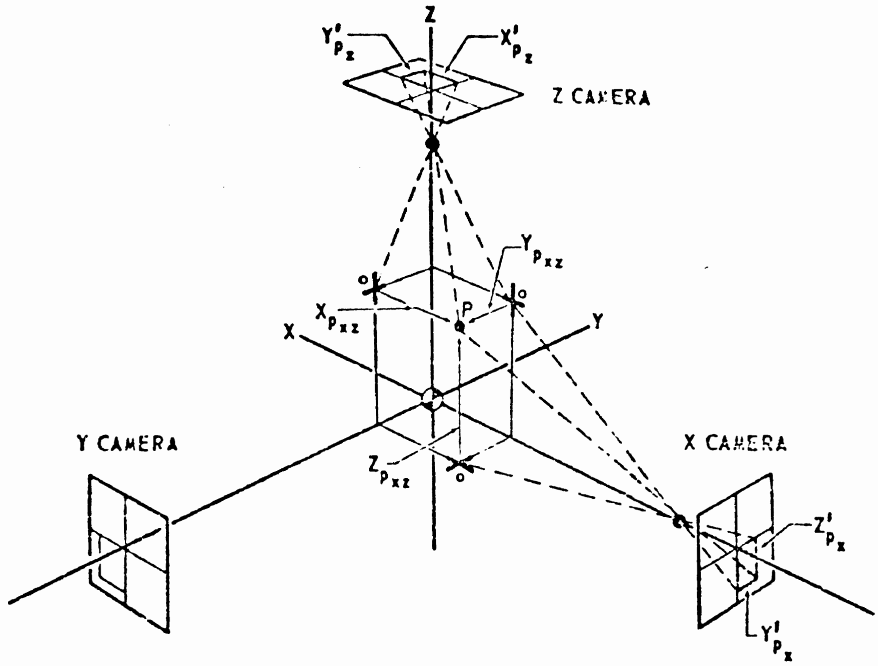
$$Z_{p_{xy(y)}} = Z'_{p_y}\left(\frac{\bar{Y}f_x - \bar{X}Y'_{p_x}}{f_x f_y - X'_{p_y}Y'_{p_x}}\right)$$

CAMERAS X AND Y

ESTIMATED COORDINATE	ANALOG COORDINATE	CAMERA
$X_{p_{xy}}$	Y'_{p_x}	X
	X'_{p_y}	Y
$Y_{p_{xy}}$	Y'_{p_x}	X
	X'_{p_y}	Y
$*Z_{p_{xy(x)}}$	Y'_{p_x}	X
	X'_{p_y}	Y
	Z'_{p_x}	X
$*Z_{p_{xy(y)}}$	Y'_{p_x}	X
	X'_{p_y}	Y
	Z'_{p_y}	Y

* The subscript p denotes that the coordinate is from the Photogrammetric Center (C_p). The first two letters of the sub-subscript indicate which cameras are used and the single letter in parentheses in the case of the Z_p estimate indicates which analog vertical coordinate (X or Y camera) is being used. This letter is necessary here since using the X and Y cameras, two separate estimates of $Z_{p_{xy}}$ are possible.

Figure E.3 X and Y camera geometry, transformation equations, and notation for estimates of "true" coordinates.



TRANSFORMATION EQUATIONS

$$X_{P_{xz(z)}} = X'_{P_z}\left(\frac{\bar{Z}f_x - \bar{X}Z'_{P_x}}{f_x f_z - X'_{P_z}Z'_{P_x}}\right)$$

$$Y_{P_{xz(x)}} = Y'_{P_x}\left(\frac{\bar{X}f_z - X'_{P_z}\bar{Z}}{f_x f_z - X'_{P_z}Z'_{P_x}}\right)$$

$$Y_{P_{xz(z)}} = Y'_{P_z}\left(\frac{\bar{Z}f_x - \bar{X}Z'_{P_x}}{f_x f_z - X'_{P_z}Z'_{P_z}}\right)$$

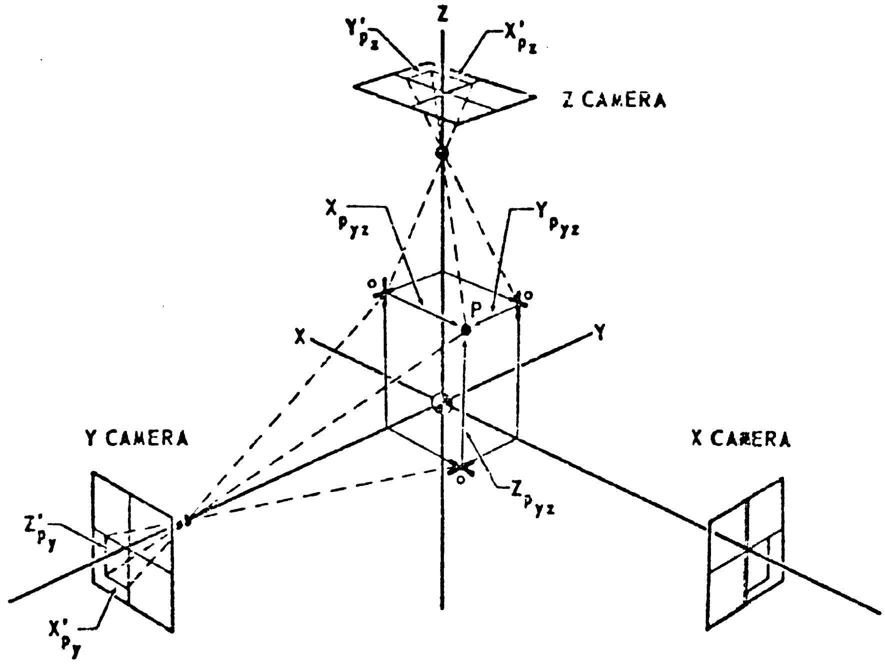
$$Z_{P_{xz(x)}} = Z'_{P_x}\left(\frac{\bar{X}f_z - \bar{Z}X'_{P_z}}{f_x f_z - X'_{P_z}Z'_{P_x}}\right)$$

CAMERAS X AND Z

ESTIMATED COORDINATE	ANALOG COORDINATE	CAMERA
$X_{P_{xz}}$	Z'_{P_x}	X
	X'_{P_z}	Z
$Z_{P_{xz}}$	Z'_{P_x}	X
	X'_{P_z}	Z
$*Y_{P_{xz(x)}}$	Y'_{P_x}	X
	Z'_{P_x}	X
	X'_{P_z}	Z
$*Y_{P_{xz(z)}}$	Y'_{P_z}	Z
	X'_{P_z}	Z
	Z'_{P_x}	X

* Using the X and Z cameras it is possible to obtain two separate estimates of Y_0; one, $Y_{P_{xz(x)}}$, from the X camera and the other, $Y_{P_{xz(z)}}$, from the Z camera.

Figure E.4 X and Z camera geometry, transformation equations, and notation for estimates of the "true" coordinates.



TRANSFORMATION EQUATIONS

$$X_{P_{yz(y)}} = X'_{P_y}\left(\frac{\bar{Y}f_z - \bar{Z}Y'_{P_z}}{{}_yf_z - Y'_{P_z}Z'_{P_y}}\right)$$

$$X_{P_{yz(z)}} = X'_{P_z}\left(\frac{\bar{Z}f_y - Z'_{P_y}\bar{Y}}{{}_yf_z - Y'_{P_z}Z'_{P_y}}\right)$$

$$Y_{P_{yz(z)}} = Y'_{P_z}\left(\frac{\bar{Z}f_y - \bar{Y}Z'_{P_y}}{{}_yf_z - Y'_{P_z}Z'_{P_y}}\right)$$

$$Z_{P_{yz(y)}} = Z'_{P_y}\left(\frac{\bar{Y}f_z - \bar{Z}Y'_{P_z}}{{}_yf_z - Y'_{P_z}Z'_{P_y}}\right)$$

CAMERAS Y AND Z

ESTIMATED COORDINATE	ANALOG COORDINATE	CAMERA
$Y_{P_{yz}}$	Z'_{P_y}	Y
	Y'_{P_z}	Z
$Z_{P_{yz}}$	Z'_{P_y}	Y
	Y'_{P_z}	Z
$*X_{P_{yz(y)}}$	X'_{P_y}	Y
	Z'_{P_y}	Y
	Y'_{P_z}	Z
$*X_{P_{yz(z)}}$	X'_{P_z}	Z
	Z'_{P_y}	Y
	Y'_{P_z}	Z

*From the Y and Z cameras we obtain two separate estimates of X_p based upon the use of either X'_{P_y} in the Y camera or X'_{P_z} in the Z camera.

Figure E.5 Y and Z camera geometry, transformation equations, and notation for estimates of the "true" coordinates.

II. Calculation of "True" Origin from Visible Origin

As noted earlier, the exact position of the imaginary intersection of the camera axes must be known in each picture (C'_{px}, C'_{py}, and C'_{pz}). Since this point in object space lies somewhere within the subject, it is not possible to mark this point in space. Another point, called the "visible origin" which is a known x, y, and z distance from the "true origin" is marked, however, and provides a means of computing the points C'_{px}, C'_{py}, and C'_{pz} in each photograph.

Referring to Figure E.6, the "visible origin", point S, is at known measured distances x_s and y_s, from the "true origin". From similar triangles:

$$\frac{x_{sy'}}{f_y} = \frac{x_s}{(\overline{Y} - y_s)} \tag{9}$$

and,

$$x'_{sy} = \frac{f_y \cdot x_s}{(\overline{Y} - y_s)} \tag{10}$$

Also,

$$\frac{y'_{sx}}{f_x} = \frac{y_s}{(\overline{X} - x_s)} \tag{11}$$

and,

$$y'_{sx} = \frac{f_x \cdot y_s}{(\overline{X} - x_s)} \tag{12}$$

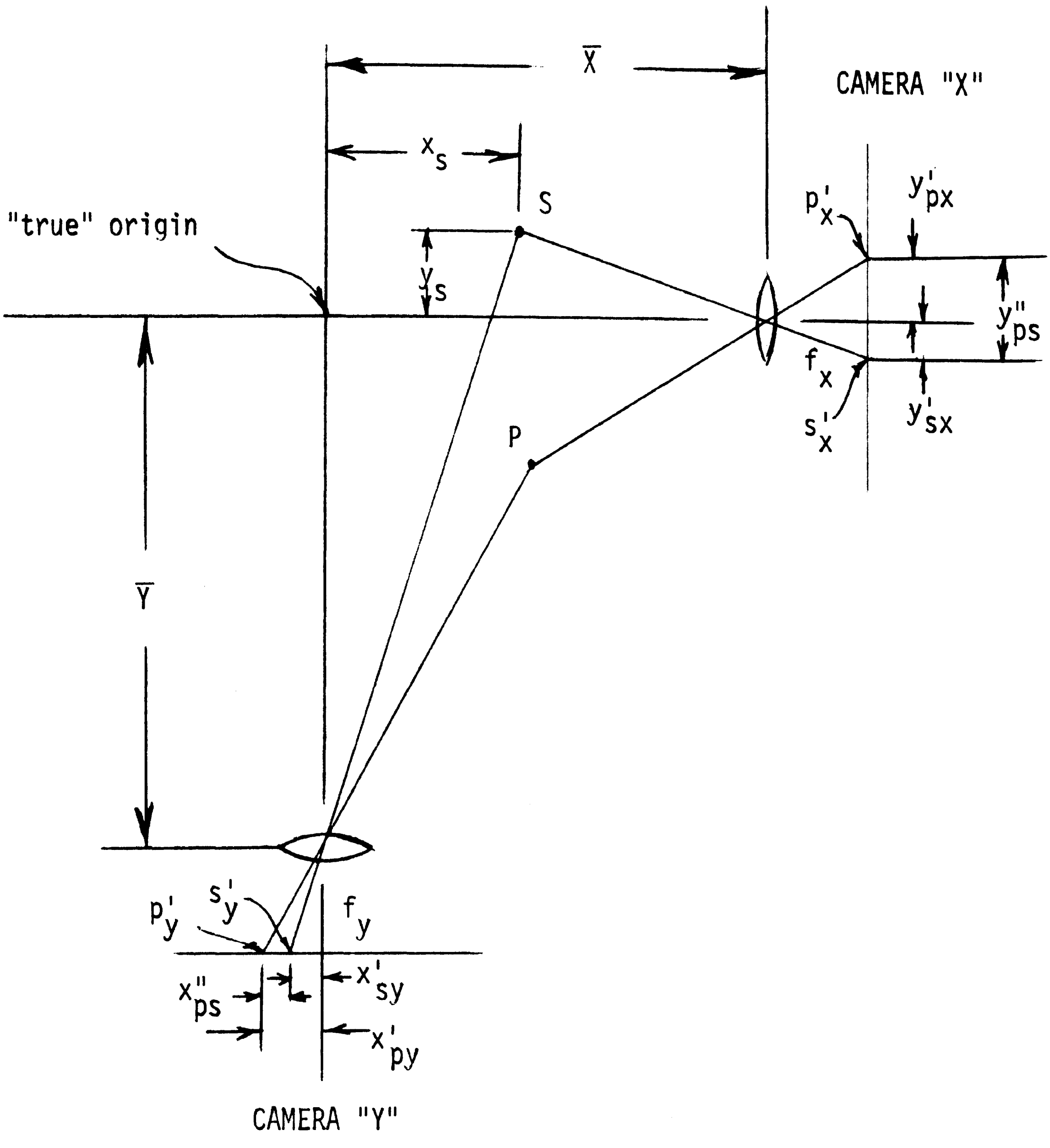


Figure E.6 Geometry for translating from visible origin (S) coordinates to "true" origin coordinates.

where the second subscript in y'_{sx} and x'_{sy} denotes the camera from which the picture was taken. Since the distance on the photograph between the visible origin and any other point can be measured (x''_{ps}, y''_{ps}), the distance from any point to the true origin can then be calculated by:

$$x'_{py} = x''_{ps} + x'_{sy}$$

and,

$$y'_{px} = y''_{ps} + y'_{sx}$$

In a similar manner this use of the visible origin may be extended to a 3-dimensional situation. The distances x'_{py}, y'_{px}, z'_{py}, etc., are then the distances needed to calculate the true position of a point, P, using the equations of Chaffee.

The actual distances x_s, y_s, and z_s for the experimental setup in this study have been measured as:

$$x_s = 6.0 \text{ in.} = 15.24 \text{ cm.}$$

$$y_s = 18.13 \text{ in.} = 46.04 \text{ cm.}$$

$$z_s = -10.39 \text{ in.} = -26.39 \text{ cm.}$$

These values were used in equations similar to (10) and (11) to compute film plane distances x'_{sy}, z'_{sy}, y'_{sx}, z'_{sz}, x'_{sz} which were then used in the computer programs for determining anthropometry and range of motion.

The x, y, and z distances of the "true origin" from the seat reference point (SRP) have also been measured so that anthropometry of the head and torso may be given relative to this more useful reference.

Measuring from "true" origin to SRP, these distances are:

$$x = 3.16 \text{ cm.}$$
$$y = 0.0 \text{ cm.}$$
$$z = -73.7 \text{ cm.}$$

III. Computation of Euler Angles

As described in Chapter 2, Section C.4 of this report, the voluntary range of cervical motion is computed by determining the Euler angles which describe the change in orientation of an orthogonal 3-axis coordinate system (Figure 2.14) attached rigidly to the subject's head. These Euler angles describe the new position relative to the Frankfort position and the axes of rotation are the anatomical axes in the head related to the Frankfort plane. While a correction for head piece tilt relative to these anatomical axes is needed to ensure that the Euler angles are computed about these anatomical axes, it will be assumed in the discussion which follows that the head piece axes line up with these anatomical axes. The order in which Euler angles are taken is also an important factor. For this study the order is yaw (α), which is rotation about an axis perpendicular to the Frankfort plane; pitch (β), which is rotation about an axis parallel to a line connecting both tragions; and roll (γ), which is rotation about an axis perpendicular to the axes of yaw and pitch.

With the subject seated with head in the Frankfort orientation, the Euler angle axes are parallel to the camera axes which will be denoted by the unit vectors $\hat{I}$, $\hat{J}$, and $\hat{K}$. These correspond to the Euler axes of roll, pitch and yaw, respectively. When the head is rotated to some new position, these headpiece axes take on a new orientation in space with respect to the inertial reference frame, and we will denote the unit vectors along the new headpiece axes in the final position by $\hat{e}_1$, $\hat{e}_2$, and $\hat{e}_3$ respectively. To achieve this new orientation, taking the Euler angle rotations in the proper order, the following rotations and intermediate orientations can be considered:

Yaw (α) : About the K-axis, resulting in an intermediate set of axes ($\hat{e}_1^*$, $\hat{e}_2^*$, $\hat{e}_3^*$).

Pitch (β): About the new intermediate $\hat{e}_2^*$ axis, resulting in another new intermediate set of axes ($\hat{e}_1^{**}$, $\hat{e}_2^{**}$, $\hat{e}_3^{**}$).

Roll (γ) : About the $\hat{e}_1^{**}$ axis, which results in the final and desired set of axes ($\hat{e}_1$, $\hat{e}_2$, $\hat{e}_3$).

Each of the above rotations can be represented by a transformation between the "previous" set of axes and the new axes.

Thus, the first rotation can be represented by:

$$(13) \qquad \begin{Bmatrix} \hat{e}_1^* \\ \hat{e}_2^* \\ \hat{e}_3^* \end{Bmatrix} = [\alpha] \begin{Bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{Bmatrix}$$

where,

$$(14) \qquad [\alpha] = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The second rotation can be represented by:

$$(15) \qquad \begin{Bmatrix} \hat{e}_1^{**} \\ \hat{e}_2^{**} \\ \hat{e}_3^{**} \end{Bmatrix} = [\beta] \begin{Bmatrix} \hat{e}_1^* \\ \hat{e}_2^* \\ \hat{e}_3^* \end{Bmatrix}$$

where,

$$(16) \qquad [\beta] = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix}$$

And the third and final rotation can be represented by:

$$(17) \qquad \begin{Bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{Bmatrix} = [\gamma] \begin{Bmatrix} \hat{e}_1^{**} \\ \hat{e}_2^{**} \\ \hat{e}_3^{**} \end{Bmatrix}$$

where,

$$(18) \qquad [\gamma] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & \sin\gamma \\ 0 & -\sin\gamma & \cos\gamma \end{bmatrix}$$

The three transformation matrices can be multiplied to yield:

$$(19) \qquad \begin{Bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{Bmatrix} = [\alpha]\ [\beta]\ [\gamma] \begin{Bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{Bmatrix}$$

where,

$$(20) \qquad [\gamma]\ [\beta]\ [\alpha] = \begin{bmatrix} \cos\alpha\cos\beta & \sin\alpha\cos\beta & -\sin\alpha \\ (\cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma) & (\cos\alpha\cos\gamma + \sin\beta\sin\gamma\sin\alpha) & \cos\beta\sin\gamma \\ (\sin\alpha\sin\gamma + \cos\alpha\sin\beta\cos\gamma) & (-\cos\alpha\sin\gamma + \sin\alpha\sin\beta\cos\gamma) & \cos\beta\cos\gamma \end{bmatrix}$$

By inspection of terms in the matrix of equation (20) and using equation (19) the following equations for the Euler angles are obtained:

$$(21) \qquad \frac{\sin\alpha\cos\beta}{\cos\alpha\cos\beta} = \frac{\hat{e}_1 \cdot \hat{J}}{\hat{e}_1 \cdot \hat{I}}$$

which gives,

$$(22) \qquad \tan^{-1}\left(\frac{\hat{e}_1 \cdot \hat{J}}{\hat{e}_1 \cdot \hat{I}}\right) = \alpha = \text{yaw}$$

$$(23) \qquad \frac{-\sin\beta}{\sin\alpha\cos\beta} = \frac{\hat{e}_1 \cdot \hat{K}}{\hat{e}_1 \cdot \hat{J}}$$

which gives,

$$(24) \qquad \tan^{-1}\left(-\sin\alpha\left(\frac{\hat{e}_1 \cdot \hat{K}}{\hat{e}_1 \cdot \hat{J}}\right)\right) = \beta = \text{pitch}$$

and,

$$(25) \qquad \frac{\cos\beta\sin\gamma}{\cos\beta\cos\gamma} = \frac{\hat{e}_2 \cdot \hat{K}}{\hat{e}_3 \cdot \hat{K}}$$

which gives,

$$(26) \qquad \tan^{-1}\left(\frac{\hat{e}_2 \cdot \hat{K}}{\hat{e}_3 \cdot \hat{K}}\right) = \gamma = \text{roll}$$

Thus, by computing the unit vectors $\hat{e}_1$, $\hat{e}_2$, and $\hat{e}_3$, using the equations of Chaffee to determine the coordinates of the endpoints of the headpiece axes, the values of α, β, and γ are then computed using equations (22), (24), and (26). In this development the positive directions of the inertial reference system axes have been taken positive from subject toward the cameras. In order to make the Euler angles compatible with most computer models where the positive sense of the $\hat{K}$ and $\hat{J}$ axes are reversed, the signs of α and β as computed above are changed, and the data have been presented in this manner. Therefore, rotation (yaw) to the right, pitch to the rear (extension), and lateral bend (roll) to the right are reported as positive angles, while rotation (yaw) to the left, pitch to the front (flexion), and lateral bend (roll) to the left are reported as negative angles.

IV. Correction for Headpiece Tilt Relative to Head Anatomical Axes

Since the Euler angles are defined about anatomical axes, and it was neither possible nor feasible to place the headpiece on each subject so that its axes were perfectly aligned with these anatomical axes, a correction transformation was needed to re-orient the headpiece axes in the final head position (i.e., after completing a range-of-motion movement) to where they would have been had the headpiece been perfectly aligned. We denote the tilted or misoriented headpiece axis system in the Frankfort plane position by $\{e'_F\}$ and both the ideal or anatomical axis system in this position, and the inertial or camera axis system (which are the same if the head is in a true Frankfort position) by $\{E\}$. The rotation matrix which describes this tilted system relative to the inertial system will be denoted by [N]. That is:

$$\begin{Bmatrix} \hat{i}'_F \\ \hat{j}'_F \\ \hat{k}'_F \end{Bmatrix} = [N] \begin{Bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{Bmatrix}$$

or,

$$i'_F = n_{11}\hat{I} + n_{12}\hat{J} + n_{13}\hat{K}$$
$$j'_F = n_{21}\hat{I} + n_{22}\hat{J} + n_{23}\hat{K}$$
$$k'_F = n_{31}\hat{I} + n_{32}\hat{J} + n_{33}\hat{K}$$

The rotation matrix, [N], is constant and also describes the orientation of the headpiece in the final head position, $\{e'\}$ relative to where it would have been had the headpiece been lined up with the head anatomical axes, $\{e\}$. Since [N] is orthogonal, $N^{-1} = N^T$, and the imaginary final position of the headpiece axis system is given by:

$$\begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} = [N^{-1}] \begin{Bmatrix} \hat{i}' \\ \hat{j}' \\ \hat{k}' \end{Bmatrix}$$

where,

$$[N^{-1}] = \begin{bmatrix} n_{11} & n_{21} & n_{31} \\ n_{12} & n_{22} & n_{23} \\ n_{13} & n_{23} & n_{33} \end{bmatrix}$$

and $\hat{i}$, $\hat{j}$, and $\hat{k}$ are the new or imaginary vectors from which the true Euler angles taken about the anatomical axes are calculated.

V. Computation of Tragion Anthropometry

In order for tragion to be seen by two cameras it was necessary that the subject's head be rotated about 45 degrees to the right. This position was the 12th or last in the range-of-motion sequence. It is obvious that with the head in this new orientation, the coordinates of tragion obtained from the Chaffee equations are not the same as the coordinates of tragion in the Frankfort position and therefore cannot be used directly with the coordinates of the other anatomical points determined from the Frankfort position. The location of the hidden tragion can, however, be determined. First, a vector in the tragion position is calculated which describes the location of tragion relative to a fixed point on the headpiece. Next, this vector is transformed by the inverse of the matrix of direction cosines which describes the tragion position relative to the Frankfort position. The location of tragion is then determined from the transformed vector and the location of this fixed point on the headpiece in the Frankfort position.

In the present study, for example, the 9 direction cosines which describe the tragion position relative to the Frankfort position were computed and used to form the transformation matrix:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

The coordinates in space of point 6 on the headpiece (see Figure 2.14) in the tragion position were computed as were the coordinates of tragion. The vector relating these two points, $\hat{T}'$, was then transformed to $\hat{T}$ by the matrix $[S]^{-1}$ and new coordinates described by $\hat{T}$ added to the coordinates of point 6 as determined from the Frankfort position photographs.

In this way it was possible to determine the anthropometry of anatomical points relative to tragion, even though the tragion position was determined from a separate set of photographs.

APPENDIX F

PHOTOGRAMMETRY COMPUTER PROGRAMS

I. General

The two computer programs contained in the following pages were written in Fortran IV for the Hewlett Packard 2115 A computer to analyze the anthropometry and range-of-motion data taken in this study. Data recorded on 35mm film were first digitized using a digitizer which converted points on the film (see Appendix D) to x, y coordinates on paper tape. The paper tapes were then read by the computer program and appropriate computations performed to achieve the final results. For the first program, NKFLX, which computes the Euler angles for range of motion, computations involved correction for camera roll, computation of headpiece vectors using the andrometric equations of Chaffee (see Appendix E), correction of vectors for headpiece tilt, and calculation of the Euler angles using equations 22, 24, and 26 given in Appendix E. For the second program, MEAS, which computes three-dimensional anthropometry of the subject seated in the Frankfort plane, computations involved correction for camera roll, computation of x, y, and z coordinates of anatomical markings using equations from Chaffee (see Appendix E), computation of x, y, and z positions of tragion in the Frankfort position using the transformations given in Appendix E, Section E of this report, and calculation of the x, y, and z distances of the anatomical points relative to the Seat Reference Point (SRP) and/or tragion.

II. Range-of-Motion Program (NKFLX)

```
FTN4
      PROGRAM NKFLX
C
      DIMENSION L1(4),L2(4),C3(4),PSI(12),PHI(12),THETA(12)
      DIMENSION X(372),Y(372),Z(372),M1(372),M2(372)
C
C     READ SUBJECT NUMBER
C      CODING SCHEME
 10   DO 100 I=1,4,1
      READ(5,25)L1(I),L2(I),C3(I)
 25   FORMAT(2I4,A1)
 100  CONTINUE
C
C     CONVERT TO SUBJECT CODE
C
      IF(L1(1).GT.2500)150,175
 150  A=2
      GO TO 200
 175  A=1
 200  IF(L1(2).GT.2500)250,225
 225  B=1
      GO TO 325
 250  IF(L1(2).GT.2600)330,75
 275  B=2
      GO TO 325
 300  B=3
 325  IF(L1(3).GT.2500)375,350
 350  C=1
      GO TO 430
 375  IF(L1(3).GT.2600)425,430
 400  C=2
      GO TO 430
 425  C=3
 430  SUBN=1
      DO 440 I=1500,2800,100
      IF(L1(4).GT.I)435,445
 435  SUBN=SUBN+1
 440  CONTINUE
 445  D=SUBN
C
C     READ IN DATA POINTS
C      DATA READ IN
 450  DO 500 I=1,372,1
      READ(5,475)M1(I),M2(I),Z(I)
 475  FORMAT(2I4,A1)
      X(I)=M1(I)/2040.0
      Y(I)=M2(I)/2040.0
 500  CONTINUE
C
C
C     ROLL COMPENSATION
C
      ARG1=(X(1)-X(2))/(Y(1)-Y(2))
      ARG2=(X(125)-X(126))/(Y(125)-Y(126))
      ARG3=(X(249)-X(250))/(Y(249)-Y(250))
```

```
      THETA1=ATAN(ARG1)
      THETA2=ATAN(ARG2)
      THETA3=ATAN(ARG3)
C
      THT1=THETA1*180./3.14
      THT2=THETA2*180./3.14
      THT3=THETA3*180./3.14
      CALL EXEC(3,21106B,-1)
      WRITE(6,507) THT1,THT2,THT3
 507  FORMAT(F5.2,3X,F5.2,3X,F5.2,///)
C
      DO 540 I=1,372,1
      IF(I.GT.124) GO TO 510
      ARG4=THETA1
      GO TO 530
 510  IF(I.GT.248) GO TO 520
      ARG4=THETA2
      GO TO 530
 520  ARG4=THETA3
 530  X1=X(I)*COS(ARG4)-Y(I)*SIN(ARG4)
      Y(I)=X(I)*SIN(ARG4)+Y(I)*COS(ARG4)
      X(I)=X1
 540  CONTINUE
C
C     DETERMINE CENTER POINTS
C
      CP1X=X(3)-.5214
      CP1Y=Y(3)+.2989
      CP2X=X(127)-.216
      CP2Y=Y(127)+.3742
      CP3X=X(251)+.4413
      CP3Y=Y(251)+.1460
C
      E=0.
      IF(D.GT.9.0) GO TO 547
      WRITE(6,548) A,B,C,E,D
 548  FORMAT("SUBJECT CODE:  ",I1,I1,I1,I1,I1)
      GO TO 555
 547  WRITE(6,550) A,B,C,D
 550  FORMAT("SUBJECT CODE:  ",I1,I1,I1,I2)
 555  WRITE(6,560)
 560  FORMAT("                    YAW      PITCH      ROLL")
C
C     COMPUTE FRANKFORT PLANE VECTORS
C
 562  CALL YZCAM(X(252),Y(252),Y(128),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X4=XT
      Y4=YT
      Z4=ZT
      CALL YZCAM(X(253),Y(253),Y(129),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X5=XT
      Y5=YT
      Z5=ZT
      CALL YZCAM(X(256),Y(256),Y(132),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X8=XT
      Y8=YT
      Z8=ZT
      CALL XZCAM(X(254),Y(254),Y(6),CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X6=XT
      Y6=YT
      Z6=ZT
      CALL XZCAM(X(255),Y(255),Y(7),CP3X,CP3Y,CP1Y,XT,YT,ZT)
      V4X=X4-X5
      V4Y=Y4-Y5
      V4Z=Z4-Z5
```

```
      CPNX=(X4+X5)/2.
      CPNY=(Y4+Y5)/2.
      CPNZ=(Z4+Z5)/2.
      V7X=X6-XT
      V7Y=Y6-YT
      V7Z=Z6-ZT
      V8X=X8-CPNX
      V8Y=Y8-CPNY
      V8Z=Z8-CPNZ
C
C     COMPUTE TILT OF HEADPIECE FROM X,Y,Z
C
      V4M=SQRT(V4X**2+V4Y**2+V4Z**2)
      V7M=SQRT(V7X**2+V7Y**2+V7Z**2)
      V8M=SQRT(V8X**2+V8Y**2+V8Z**2)
      S11=V4X/V4M
      S12=V4Y/V4M
      S13=V4Z/V4M
      S21=V7X/V7M
      S22=V7Y/V7M
      S23=V7Z/V7M
      S31=V8X/V8M
      S32=V8Y/V8M
      S33=V8Z/V8M
C
C     COMPUTE VECTORS AND EULER ANGLES FOR
C     POSITIONS 2 THRU 11
C
      DO 2000 I=2,11
      CP1X=X(I*10.-3)-.5214
      CP1Y=Y(I*10.-3)+.2989
      CP2X=X(I*10.+121)-.2160
      CP2Y=Y(I*10.+121)+.3742
      CP3X=X(I*10.+235)+.4413
      CP3Y=Y(I*10.+235)+.1460
      J=2
      V45P=1
      V6P=1
      V5P=1
      V456P=1
      V67P=1
      V4P=1
      V7P=1
      V8P=1
      V8PP=1
      IF(X(I*10.+248).GT.1.90) V6P=0.
      IF(X(I*10.+249).GT.1.90) V7P=0.
      IF(X(I*10.+250).GT.1.90) V8PP=0.
      IF(I.EQ.2) GO TO 630
      IF(I.EQ.3) GO TO 630
      IF(I.EQ.4) GO TO 630
      IF(I.EQ.7) GO TO 630
      IF(I.EQ.8) GO TO 630
      IF(X(I*10.+124).GT.1.90) V6P=0.
      IF(X(I*10.+125).GT.1.90) V7P=0.
      IF(X(I*10.+126).GT.1.90) V8PP=0.
      CALL YECAM(X(I*10.+248),Y(I*10.+248),Y(I*10.+124),
     *CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X6=XT
      Y6=YT
      Z6=ZT
      CALL YECAM(X(I*10.+249),Y(I*10.+249),Y(I*10.+125),
     *CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X7=XT
```

```
      Y7=YT
      Z7=ZT
      CALL YZCAM(X(I*10.+250),Y(I*10.+250),Y(I*10.+126),
     *CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X88=XT
      Y88=YT
      Z88=ZT
      GO TO 640
630   J=0
      IF(X(I*10.).GT.1.90) V6P=0.
      IF(X(I*10.+1).GT.1.90) V7P=0.
      IF(X(I*10.+2).GT.1.90) V8PP=0.
      CALL XZCAM(X(I*10.+248),Y(I*10.+248),Y(I*10.),
     *CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X6=XT
      Y6=YT
      Z6=ZT
      CALL XZCAM(X(I*10.+249),Y(I*10.+249),Y(I*10.+1),
     *CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X7=XT
      Y7=YT
      Z7=ZT
      CALL XZCAM(X(I*10.+250),Y(I*10.+250),Y(I*10.+2),
     *CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X88=XT
      Y88=YT
      Z88=ZT
      XXT=XT
      YYT=YT
      ZZT=ZT
640   V7PX=X6-X7
      V7PY=Y6-Y7
      V7PZ=Z6-Z7
660   IF(X(I*10.+246).GT.1.90) V4P=0.
      IF(X(I*10.+247).GT.1.90) V5P=0.
      IF(I.EQ.4) GO TO 665
      IF(J.EQ.0) GO TO 670
      GO TO 666
665   IF(X(I*10.-1.).GT.1.90) GO TO 670
666   IF(X(I*10.-2).GT.1.90) V4P=0.
      IF(X(I*10.-1).GT.1.90) V5P=0.
      CALL XZCAM(X(I*10.+246),Y(I*10.+246),Y(I*10.-2),
     *CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X4=XT
      Y4=YT
      Z4=ZT
      CALL XZCAM(X(I*10.+247),Y(I*10.+247),Y(I*10.-1),
     *CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X5=XT
      Y5=YT
      Z5=ZT
      IF(X(I*10.+250).GT.1.90) V8P=0.
      IF(X(I*10.+2).GT.1.90) V8P=0.
      CALL XZCAM(X(I*10.+250),Y(I*10.+250),Y(I*10.+2),
     *CP3X,CP3Y,CP1Y,XT,YT,ZT)
      GO TO 680
670   IF(X(I*10.+122).GT.1.90) V4P=0.
      IF(X(I*10.+123).GT.1.90) V5P=0.
      CALL YZCAM(X(I*10.+246),Y(I*10.+246),Y(I*10.+122),
     *CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X4=XT
      Y4=YT
      Z4=ZT
      CALL YZCAM(X(I*10.+247),Y(I*10.+247),Y(I*10.+123),
     *CP3X,CP3Y,CP2Y,XT,YT,ZT)
```

```
      X5=XT
      Y5=YT
      Z5=ZT
      IF(X(I*10.+250).GT.1.90) V8P=0.
      IF(X(I*10.+126).GT.1.90) V8P=0.
      CALL YZCAM(X(I*10.+250),Y(I*10.+250),Y(I*10.+126),
     *CP3X,CP3Y,CP2Y,XT,YT,ZT)
680   IF(V4P.EQ.0) GO TO 690
      IF(V5P.EQ.0) GO TO 690
      GO TO 695
690   V45P=0.
      IF(V6P.EQ.0) GO TO 700
      IF(V7P.EQ.0) GO TO 700
      CPX=(X7+X6)/2.
      CPY=(Y7+Y6)/2.
      CPZ=(Z7+Z6)/2.
      IF(V8PP.EQ.0) V8P=0.
      V8PX=X88-CPX
      V8PY=Y88-CPY
      V8PZ=Z88-CPZ
      IF(V4P.EQ.0) GO TO 693
      V4PX=X4-CPX
      V4PY=Y4-CPY
      V4PZ=Z4-CPZ
      GO TO 701
693   IF(V5P.EQ.0) GO TO 700
      V4PX=CPX-X5
      V4PY=CPY-Y5
      V4PZ=CPZ-Z5
      GO TO 701
695   CPX=(X4+X5)/2.
      CPY=(Y4+Y5)/2.
      CPZ=(Z4+Z5)/2.
      V4PX=X4-X5
      V4PY=Y4-Y5
      V4PZ=Z4-Z5
      V8PX=XT-CPX
      V8PY=YT-CPY
      V8PZ=ZT-CPZ
      GO TO 701
700   V456P=0.
701   IF(V6P.EQ.0) GO TO 706
      IF(V7P.EQ.0) GO TO 706
      GO TO 709
706   IF(V45P.EQ.0) GO TO 708
      IF(V6P.EQ.0) GO TO 707
      V7PX=X6-CPX
      V7PY=Y6-CPY
      V7PZ=Z6-CPZ
      GO TO 709
707   IF(V7P.EQ.0) GO TO 708
      V7PX=CPX-X7
      V7PY=CPY-Y7
      V7PZ=CPZ-Z7
      GO TO 709
708   V67P=0.
709   V4PM=SQRT(V4PX**2+V4PY**2+V4PZ**2)
      V7PM=SQRT(V7PX**2+V7PY**2+V7PZ**2)
      V8PM=SQRT(V8PX**2+V8PY**2+V8PZ**2)
      V4PX=V4PX/V4PM
      V4PY=V4PY/V4PM
      V4PZ=V4PZ/V4PM
      V7PX=V7PX/V7PM
      V7PY=V7PY/V7PM
```

```
      V7PZ=V7PZ/V7PM
      V8PX=V8PX/V8PM
      V8PY=V8PY/V8PM
      V8PZ=V8PZ/V8PM
      IF(V456P.EQ.0) GO TO 710
C
C     CORRECT FOR HEADPIECE TILT
C
      U4PX=S11*V4PX+S21*V7PX+S31*V8PX
      U4PY=S11*V4PY+S21*V7PY+S31*V8PY
      U4PZ=S11*V4PZ+S21*V7PZ+S31*V8PZ
      U4P=SQRT(U4PX**2+U4PY**2+U4PZ**2)
      ARG1A=U4PY/U4P
      ARG1B=U4PX/U4P
      PSI(I)=ATAN(ARG1A/ARG1B)*180./3.1416
      ARG2A=U4PZ/U4P
      ARG2B=U4PY/U4P
      PHI(I)=ATAN(-(ARG2A/ARG2B)*SIN(PSI(I)*3.1416/180.))*180./3.14
      PSI(I)=-PSI(I)
      PHI(I)=-PHI(I)
      GO TO 715
 710  PSI(I)=999.9
      PHI(I)=999.9
 715  IF(V8P.EQ.0) GO TO 720
      IF(V67P.EQ.0) GO TO 720
C
C     CORRECT VECTORS 6 AND 8 FOR HEADPIECE TILT
C
      U7PX=S12*V4PX+S22*V7PX+S32*V8PX
      U7PY=S12*V4PY+S22*V7PY+S32*V8PY
      U7PZ=S12*V4PZ+S22*V7PZ+S32*V8PZ
      U7P=SQRT(U7PX**2+U7PY**2+U7PZ**2)
      U8PX=S13*V4PX+S23*V7PX+S33*V8PX
      U8PY=S13*V4PY+S23*V7PY+S33*V8PY
      U8PZ=S13*V4PZ+S23*V7PZ+S33*V8PZ
      U8P=SQRT(U8PX**2+U8PY**2+U8PZ**2)
      ARG3A=U7PZ/U7P
      ARG3B=U8PZ/U8P
      THETA(I)=ATAN(ARG3A/ARG3B)*180./3.1416
      GO TO 1230
 720  THETA(I)=999.9
 1230 WRITE(6,1520)I,PSI(I),PHI(I),THETA(I)
 1520 FORMAT("POSITION: ",I2,"    ",F5.1,"      ",F5.1,"       ",F5.1)
 2000 CONTINUE
 2010 READ(1,2020) I
      IF(I.EQ.8) GO TO 2025
      GO TO 10
 2020 FORMAT(I1)
 2025 END
C
      SUBROUTINE YZCAM(X3D,Y3D,Y2D,CD3X,CD3Y,CD2Y,XT,YT,ZT)
      ZPR=Y2D-CD2Y
      XPR=Y3D-CD3Y
      YPR=CD3X-X3D
      YT=YPR*(84.7*4.28-133.1*ZPR)/(4.28*2.28-YPR*ZPR)
      ZT=ZPR*(133.1*2.28-84.7*YPR)/(4.28*2.28-YPR*ZPR)
      XT=XPR*(84.7*4.28-133.1*ZPR)/(4.28*2.28-YPR*ZPR)
      RETURN
      END
C
C
      SUBROUTINE XZCAM(X3D,Y3D,Y1D,CD3X,CD3Y,CD1Y,XT,YT,ZT)
      XPR=Y3D-CD3Y
      ZPR=Y1D-CD1Y
```

```
YPR=CD3X-X3D
XT=XPR*(84.7*4.26-140.2*ZPR)/(4.26*2.28-XPR*ZPR)
YT=YPR*(84.7*4.26-140.2*ZPR)/(4.26*2.28-XPZZPR)
ZT=ZPR*(140.2*2.28-84.7*XPR)/(4.26*2.28-XPR*ZPR)
RETURN
END
ENDS
```

III. Three Dimensional Anthropometry Program (MEAS)

```
FTN4
      PROGRAM MEAS
      DIMENSION L1(4),L2(4),C3(4),X(372),Y(372),M1(372),M2(372)
C
C     READ IN SUBJECT NUMBER
C      CODING SCHEME
 10   DO 100 I=1,4,1
      READ(5,25) L1(I),L2(I),C3(I)
 25   FORMAT(2I4,A1)
 100  CONTINUE
C
      IF(L1(1).GT.2500)150,175
 150  A=2
      GO TO 200
 175  A=1
 200  IF(L1(2).GT.2500)250,225
 225  B=1
      GO TO 325
 250  IF(L1(2).GT.2600)300,275
 275  B=2
      GO TO 325
 300  B=3
 325  IF(L1(3).GT.2500)375,350
 350  C=1
      GO TO 430
 375  IF(L1(3).GT.2600)425,400
 400  C=2
      GO TO 430
 425  C=3
 430  SUBN=1
      DO 440 I=1500,2800,100
      IF(L1(4).GT.I)435,445
 435  SUBN=SUBN+1
 440  CONTINUE
 445  D=SUBN
C
C      DATA READ IN
C
 450  DO 500 I=1,372,1
      READ(5,475)M1(I),M2(I),X(I)
 475  FORMAT(2I4,A1)
      X(I)=M1(I)/2040.
      Y(I)=M2(I)/2040.
 500  CONTINUE
C
C     ROLL COMPENSATION
C
      ARG1=(X(1)-X(2))/(Y(1)-Y(2))
      ARG2=(X(125)-X(126))/(Y(125)-Y(126))
      ARG3=(X(249)-X(250))/(Y(249)-Y(250))
      THETA1=ATAN(ARG1)
      THETA2=ATAN(ARG2)
      THETA3=ATAN(ARG3)
C
      DO 540 I=1,372,1
      IF(I.GT.124) GO TO 510
      ARG4=THETA1
      GO TO 530
 510  IF(I.GT.248) GO TO 520
```

```
      ARG4=THETA2
      GO TO 530
 520  ARG4=THETA3
 530  X1=X(I)*COS(ARG4)-Y(I)*SIN(ARG4)
      Y(I)=X(I)*SIN(ARG4)+Y(I)*COS(ARG4)
      X(I)=X1
 540  CONTINUE
C
C
C      DETERMINATION OF THE CENTER POINT
C
      CP1X=X(3)-0.5214
      CP1Y=Y(3)+0.2989
      CP2X=X(127)-0.2160
      CP2Y=Y(127)+0.3742
      CP3X=X(251)+0.4413
      CP3Y=Y(251)+0.1460
      SP1X=X(117)-.5214
      SP1Y=Y(117)+.2989
      SP2X=X(241)-.2160
      SP2Y=Y(241)+.3742
      SP3X=X(365)+.4413
      SP3Y=Y(365)+.1460
      CM=2.54
      XN=999.9
      ZD=73.7
C
C      ANTHROPOMETRY
C
C     LEFT SHOULDER
C
      N1=1
      IF(X(9).GT.1.90) GO TO 600
      IF(X(133).GT.1.90) GO TO 625
      CALL YXCAM(X(133),Y(133),X(9),CP2X,CP2Y,CP1X,XT,YT,ZT)
      XAB=YT*CM
      XAH=ZT*CM+ZD
      XAD=XT*CM-3.16
      GO TO 626
 600  N1=2
      IF(X(133).GT.1.90) GO TO 625
      IF(X(257).GT.1.90) GO TO 625
      CALL YZCAM(X(257),Y(257),Y(133),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      XAB=YT*CM*.89
      XAH=ZT*CM+ZD
      XAD=XT*CM*.89-3.16
      GO TO 626
 625  XAH=XN
      XAD=XN
      XAB=XN
C
C     SHOULDER BREADTH
C
 626  N2=1
      IF(X(9).GT.1.90) GO TO 630
      IF(X(11).GT.1.90) GO TO 630
      IF(X(133).GT.1.90) GO TO 635
      CALL XYCAM(X(9),Y(9),X(133),CP1X,CP1Y,CP2X,XT,YT,ZT)
      YB=YT
      CALL XYCAM(X(11),Y(11),X(133),CP1X,CP1Y,CP2X,XT,YT,ZT)
      BAB=(YB-YT)*CM
      GO TO 640
 630  N2=2
      IF(X(257).GT.1.90) GO TO 635
```

```
      IF(X(259).GT.1.90) GO TO 635
      IF(X(133).GT.1.90) GO TO 635
      CALL YZCAM(X(257),Y(257),Y(133),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      YB=YT
      CALL YZCAM(X(259),Y(259),Y(133),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      BAB=(YB-YT)*CM*.89
      GO TO 640
 635  BAB=XN
C
C     SUPERSTERNALE
C
 640  IF(X(10).GT.1.90) GO TO 645
      IF(X(134).GT.1.90) GO TO 645
      CALL XYCAM(X(10),Y(10),X(134),CP1X,CP1Y,CP2X,XT,YT,ZT)
      SSB=YT*CM
      SSH=ZT*CM+ZD
      SSD=XT*CM-3.16
      GO TO 650
 645  SSH=XN
      SSD=XN
      SSB=XN
C
C     CERVICALE
C
 650  IF(X(135).GT.1.90) GO TO 655
      IF(X(10).GT.1.90) GO TO 655
      CALL YXCAM(X(135),Y(135),X(10),CP2X,CP2Y,CP1X,XT,YT,ZT)
      CB=YT*CM
      CH=ZT*CM+ZD
      CD=XT*CM-3.16
      GO TO 660
 655  CH=XN
      CD=XN
      CB=XN
C
C     TRAGION
C
C     COMPUTE VECTOR FROM HEADPIECE PT. 6 TO TRAGION
C     IN TRAGION PICTURE
C
 660  IF(X(123).GT.1.90) GO TO 690
      IF(X(247).GT.1.90) GO TO 690
      IF(X(120).GT.1.90) GO TO 690
      IF(X(244).GT.1.90) GO TO 690
      CALL XYCAM(X(123),Y(123),X(247),SP1X,SP1Y,SP2X,XT,YT,ZT)
      XTR=XT
      YTR=YT
      ZTR=ZT
      CALL XYCAM(X(120),Y(120),X(244),SP1X,SP1Y,SP2X,XT,YT,ZT)
      XTR=XTR-XT
      YTR=YTR-YT
      ZTR=ZTR-ZT
C
C     COMPUTE TILT OF HEAD PIECE RE X,Y,Z IN FRANKFORT PL.
C
      CALL YZCAM(X(252),Y(252),Y(128),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X4=XT
      Y4=YT
      Z4=ZT
      CALL YZCAM(X(253),Y(253),Y(129),CP3X,CP3Y,CP2Y,XT,YT,ZT)
      X5=XT
      Y5=YT
      Z5=ZT
      CALL YZCAM(X(256),Y(256),Y(132),CP3X,CP3Y,CP2Y,XT,YT,ZT)
```

```
      X8=XT
      Y8=YT
      Z8=ZT
      CALL XZCAM(X(254),Y(254),Y(6),CP3X,CP3Y,CP1Y,XT,YT,ZT)
      X6=XT
      Y6=YT
      Z6=ZT
      CALL XZCAM(X(255),Y(255),Y(7),CP3X,CP3Y,CP1Y,XT,YT,ZT)
      V4X=X4-X5
      V4Y=Y4-Y5
      V4Z=Z4-Z5
      CPNX=(X4+X5)/2.
      CPNY=(Y4+Y5)/2.
      CPNZ=(Z4+Z5)/2.
      V7X=X6-XT
      V7Y=Y6-YT
      V7Z=Z6-ZT
      V8X=X8-CPNX
      V8Y=Y8-CPNY
      V8Z=Z8-CPNZ
      V4M=SQRT(V4X**2+V4Y**2+V4Z**2)
      V7M=SQRT(V7X**2+V7Y**2+V7Z**2)
      V8M=SQRT(V8X**2+V8Y**2+V8Z**2)
      S11=V4X/V4M
      S12=V4Y/V4M
      S13=V4Z/V4M
      S21=V7X/V7M
      S22=V7Y/V7M
      S23=V7Z/V7M
      S31=V8X/V8M
      S32=V8Y/V8M
      S33=V8Z/V8M
C
C     COMPUTE 9 DIRECTION COSINES OF TRAGION POSITION
C     RE FRANKFORT POSITION
C
      CALL YZCAM(X(366),Y(366),Y(242),SP3X,SP3Y,SP2Y,XT,YT,ZT)
      X4P=XT
      Y4P=YT
      Z4P=ZT
      CALL YZCAM(X(367),Y(367),Y(243),SP3X,SP3Y,SP2Y,XT,YT,ZT)
      X5=XT
      Y5=YT
      Z5=ZT
      CALL YZCAM(X(370),Y(370),Y(246),SP3X,SP3Y,SP2Y,XT,YT,ZT)
      X8=XT
      Y8=YT
      Z8=ZT
      CALL XZCAM(X(368),Y(368),Y(120),SP3X,SP3Y,SP1Y,XT,YT,ZT)
      X6P=XT
      Y6P=YT
      Z6P=ZT
      CALL XZCAM(X(369),Y(369),Y(121),SSX,SP3Y,SP1Y,XT,YT,ZT)
      V4PX=X4P-X5
      V4PY=Y4P-Y5
      V4PZ=Z4P-Z5
      CPX=(X4P+X5)/2.
      CPY=(Y4P+Y5)/2.
      CPZ=(Z4P+Z5)/2.
      V8PX=X8-CPX
      V8PY=Y8-CPY
      V8PZ=Z8-CPZ
      V7PX=X6P-XT
      V7PY=Y6P-YT
```

```
      V7PZ=Z6P-ZT
      V4PM=SQRT(V4PX**2+V4PY**2+V4PZ**2)
      V7PM=SQRT(V7PX**2+V7PY**2+V7PZ**2)
      V8PM=SQRT(V8PX**2+V8PY**2+V8PZ**2)
      V4PX=V4PX/V4PM
      V4PY=V4PY/V4PM
      V4PZ=V4PZ/V4PM
      V7PX=V7PX/V7PM
      V7PY=V7PY/V7PM
      V7PZ=V7PZ/V7PM
      V8PX=V8PX/V8PM
      V8PY=V8PY/V8PM
      V8PZ=V8PZ/V8PM
C
C     CORRECT FOR HEADPIECE TILT
C
      U4PX=S11*V4PX+S21*V7PX+S31*V8PX
      U4PY=S11*V4PY+S21*V7PY+S31*V8PY
      U4PZ=S11*V4PZ+S21*V7PZ+S31*V8PZ
      U7PX=S12*V4PX+S22*V7PX+S32*V8PX
      U7PY=S12*V4PY+S22*V7PY+S32*V8PY
      U7PZ=S12*V4PZ+S22*V7PZ+S32*V8PZ
      U8PX=S13*V4PX+S23*V7PX+S33*V8PX
      U8PY=S13*V4PY+S23*V7PY+S33*V8PY
      U8PZ=S13*V4PZ+S23*V7PZ+S33*V8PZ
      U4P=SQRT(U4PX**2+U4PY**2+U4PZ**2)
      U7P=SQRT(U7PX**2+U7PY**2+U7PZ**2)
      U8P=SQRT(U8PX**2+U8PY**2+U8PZ**2)
      C11=U4PX/U4P
      C12=U4PY/U4P
      C13=U4PZ/U4P
      C21=U7PX/U7P
      C22=U7PY/U7P
      C23=U7PZ/U7P
      C31=U8PX/U8P
      C32=U8PY/U8P
      C33=U8PZ/U8P
C
C     TRANSFORM 6-TRAGION VECTOR FOR FRANKFORT PLANE POSITION
C
      XTRG=C11*XTR+C12*YTR+C13*ZTR
      YTRG=C21*XTR+C22*YTR+C23*ZTR
      ZTRG=C31*XTR+C32*YTR+C33*ZTR
      CALL XYCAM(X(6),Y(6),X(130),CP1X,CP1Y,CP2X,XT,YT,ZT)
C
C     COMPUTE TRAGION POSITION IN FRANKFORT PLANE
C
      TBSRP=(YT+YTRG)*CM
      THSRP=(ZT+ZTRG)*CM+ZD
      TDSRP=(XT+XTRG)*CM-3.16
      GO TO 695
 690  THSRXN
      TDSRP=XN
      TBSRP=XN
C
C     TRAGION RE CERVICALE
C
 695  IF(CH.EQ.XN) GO TO 700
      IF(THSREQ.XN) GO TO 700
      THCER=THSRP-CH
      TDCER=TDSRP-CD
      GO TO 710
 700  THCER=XN
      TDCER=XN
C
```

```
C     INFRAORBITALE RE TRAGION
C
 710  IF(X(12).GT.1.90) GO TO 718
      IF(X(136).GT.1.90) GO TO 718
      CALL XYCAM(X(12),Y(12),X(136),CP1X,CP1Y,CP2X,XT,YT,ZT)
      XIH=ZT*CM+ZD
      XID=XT*CM-3.16
      XIB=YT*CM
      IF(THSRP.EQ.XN) GO TO 720
      EIHTR=ZT*CM+ZD-THSRP
      EIDTR=XT*CM-3.16-TDSRP
      GO TO 730
 718  XIH=XN
      XID=XN
      XIB=XN
 720  EIHTR=XN
      EIDTR=XN
C
C     GLABELLA
C
 730  IF(X(139).GT.1.90) GO TO 740
      IF(X(15).GT.1.90) GO TO 740
      CALL YXCAM(X(139),Y(139),X(15),CP2X,CP2Y,CP1X,XT,YT,ZT)
      GBSRP=YT*CM
      GHSRP=ZT*CM+ZD
      GDSRP=XT*CM-3.16
      IF(THSRP.EQ.XN) GO TO 745
      GHTR=GHSRP-THSRP
      GDTR=GDSRP-TDSRP
      GO TO 750
 740  GHSRP=XN
      GDSRP=XN
      GBSRXN
 745  GHTR=XN
      GDTR=XN
C
C     EYE ELLIPSE POINT
C
 750  IF(X(138).GT.1.90) GO TO 760
      IF(X(14).GT.1.90) GO TO 760
      CALL YXCAM(X(138).Y(138),X(14),CP2X,CP2Y,CP1X,XT,YT,ZT)
      EBSRP=YT*CM
      EHSRP=ZT*CM+ZD
      EDSRP=XT*CM-3.16
      IF(GBSRP.EQ.XN) GO TO 752
C
C     EYE ELLIPSE WIDTH RE GLABELLA
C
      EEGB=EBSRP-GBSRP
      GO TO 755
 752  EEGB=XN
 755  IF(THSRP.EQ.XN) GO TO 765
      EHTR=EHSRP-THSRP
      EDTR=EDSRP-TDSRP
      GO TO 770
 760  EHSRP=XN
      EDSRP=XN
      EEGB=XN
      EBSRP=XN
 765  EHTR=XN
      EDTR=XN
C
C     ECTOCANTHUS
C
 770  IF(X(137).GT.1.90) GO TO 775
```

```
      IF(X(13).GT.1.90) GO TO 775
      CALL YXCAM(X(137),Y(137),X(13),CP2X,CP2Y,CP1X,XT,YT,ZT)
      EB=YT*CM
      EH=ZT*CM+ZD
      ED=XT*CM-3.16
      IF(THSREQ.XN) GO TO 780
      ECHTR=ZT*CM+ZD-THSRP
      ECDTR=XT*CM-3.16-TDSRP
      GO TO 800
775   EB=XN
      EH=XN
      ED=XN
780   ECHTR=XN
      ECDTR=XN
C
C     PRINT OUT RESULTS
C
800   CALL EXEC(3,21106B,-1)
      E=0.
      IF(D.GT.9.0) GO TO 803
      WRITE(6,801) A,B,C,E,D
801   FORMAT("SUBJECT CODE:  ",I1,I1,I1,I1,I1,/)
      GO TO 807
803   WRITE(6,805) A,B,C,D
805   FORMAT("SUBJECT CODE:  ",I1,I1,I1,I2,/)
807   WRITE(6,810) XAH
810   FORMAT("LEFT SHOULDER HEIGHT RE SRP                          ",F5.1)
      WRITE(6,820) XAD
820   FORMAT("LEFT SHOULDER DEPTH RE SRP                           ",F5.1)
      WRITE(6,830) N1,BAB
830   FORMAT("SHOULDER BREADTH-",I1,"                                   ",F5.1)
      WRITE(6,840) CH
840   FORMAT("CERVICALE-C7-HEIGHT RE SRP                           ",F5.1)
      WRITE(6,850) CD
850   FORMAT("CERVICALE-C7-DEPTH RE SRP                            ",F5.1)
      WRITE(6,860) SSH
860   FORMAT("SUPRASTERNALE HEIGHT RE SRP                          ",F5.1)
      WRITE(6,870) SSD
870   FORMAT("SUPRASTERNALE DEPTH RE SRP                           ",F5.1)
      WRITE(6,880) THSRP
880   FORMAT("LEFT TRAGION HEIGHT RE SRP                           ",F5.1)
      WRITE(6,890) TDSRP
890   FORMAT("LEFT TRAGION DEPTH RE SRP                            ",F5.1)
      WRITE(6,900) THCER
900   FORMAT("LEFT TRAGION HEIGHT RE CERVICALE                     ",F5.1)
      WRITE(6,910) TDCER
910   FORMAT("LEFT TRAGION DEPTH RE CERVICALE                      ",F5.1)
      WRITE(6,920) EIHTR
920   FORMAT("LEFT EYE INFRAORBITALE HT. RE TRAG.                  ",F5.1)
      WRITE(6,930) EIDTR
930   FORMAT("LEFTEYE INFRAORBITALE DEPTH RE TRAG.                ",F5.1)
      WRITE(6,940) GHSRP
940   FORMAT("GLABELLA HEIGHT RE TRAGION                           ",F5.1)
      WRITE(6,950) GDTR
950   FORMAT("GLABELLA DEPTH RE TRAGION                            ",F5.1)
      WRITE(6,960) GHSRP
960   FORMAT("GLABELLA HEIGHT RE SRP                               ",F5.1)
      WRITE(6,970) GDSRP
970   FORMAT("GLABELLA DEPTH RE SRP                                ",F5.1)
      WRITE(6,980) EHSRP
980   FORMAT("LEFT EYE ELLIPSE PT. HEIGHT RE SRP                   ",F5.1)
      WRITE(6,1000) EDSRP
1000  FORMAT("LEFT EYE ELLIPSE PT. DEPTH RE SRP                    ",F5.1)
      WRITE(6,1010) EHTR
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```
1010 FORMAT("LEFT EYE ELLIPSE PT. HEIGHT RE TRAG.              ",F5.1)
     WRITE(6,1020) EDTR
1020 FORMAT("LEFT EYE ELLIPSE PT DEPTH RE TRAG.               ",F5.1)
     WRITE(6,1025) EEG3
1025 FORMAT("LEFT EYE ELLIPSE POINT WIDTH RE GLABELLA         ",F5.1)
     WRITE(6,1030) ECHTR
1030 FORMAT("LEFT EYE ECTOCANTHUS HEIGHT RE TRAG.             ",F5.1)
     WRITE(6,1040) ECDTR
1040 FORMAT("LEFT EYE ECTOCANTHUS DEPTH RE TRAG.              ",F5.1)
     WRITE(6,1050)
1050 FORMAT(////,"MEASURE RE SRP          X        Y         Z",/)
     WRITE(6,1060) N2,XAD,XAB,XAH
1060 FORMAT("LEFT SHOULDER-",I1,"      ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1070) CD,CB,CH
1070 FORMAT("CERVICALE-C7         ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1080) SSD,SSB,SSH
1080 FORMAT("SUPRASTERNALE        ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1090) TDSRP,TBSRP,THSRP
1090 FORMAT("TRAGION              ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1100) XID,XIB,XIH
1100 FORMAT("INFRAORBITALE        ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1110) GDSRP,GBSRP,GHSRP
1110 FORMAT("GLABELLA             ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1120) EDSRP,EBSRP,EHSRP
1120 FORMAT("EYE ELLIPSE PT.      ",F5.1,"    ",F5.1,"    ",F5.1)
     WRITE(6,1130) ED,EB,EH
1130 FORMAT("ECTOCANTHUS          ",F5.1,"    ",F5.1,"    ",F5.1)
     READ(1,1140) I
     IF(I.EQ.8) GO TO 2000
     GO TO 10
1140 FORMAT(I1)
2000 END
C
C    CHAFFEE EQUATION SUBROUTINES
C
     SUBROUTINE YXCAM(X2D,Y2D,X1D,CD2X,CD2Y,CD1X,XT,YT,ZT)
     XPR=CD2X-X2D
     YPR=X1D-CD1X
     ZPR=Y2D-CD2Y
     XT=XPR*(133.1*4.26-140.2*YPR)/(4.26*4.28-XPR*YPR)
     YT=YPR*(140.2*4.28-133.1*XPR)/(4.26*4.28-XPR*YPR)
     ZT=ZPR*(133.1*4.26-140.2*YPR)/(4.26*4.28-XPZYPR)
C
     RETURN
     END
C
C
     SUBROUTINE YZCAM(X3D,Y3D,Y2D,CD3X,CD3Y,CD2Y,XT,YT,ZT)
     ZPR=Y2D-CD2Y
     XPR=Y3D-CD3Y
     YPR=CD3X-X3D
     YT=YPR*(84.7*4.28-133.1*ZPR)/(4.28*2.28-YPR*ZR)
     ZT=ZPR*(133.1*2.28-84.7*YPR)/(4.28*2.28-YPR*ZPR)
     XT=XPR*(84.7*4.28-133.1*ZPR)/(4.28*2.28-YPR*ZPR)
     RETURN
     END
C
C
     SUBROUTINE XZCAM(X3D,Y3D,Y1D,CD3X,CD3Y,CD1Y,XT,YT,ZT)
     XPR=Y3D-CD3Y
     ZPR=Y1D-CD1Y
     YPR=CD3X-X3D
     XT=XPR*(84.7*4.26-140.2*ZPR)/(4.26*2.28-XPZZPR)
     YT=YPR*(84.7*4.26-140.2*ZPR)/(4.26*2.28-XPR*ZPR)
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```
      ZT=ZPR*(140.2*2.28-84.7*XPR)/(4.26*2.28-XPR*ZPR)
      RETURN
      END
C
C
      SUBROUTINE XYCAM(X1D,Y1D,X2D,CD1X,CD1Y,CD2X,XT,YT,ZT)
      YPR=X1D-CD1X
      XPR=CD2X-X2D
      ZPR=Y1D-CD1Y
      XT=XPR*(133.1*4.26-140.2*YPR)/(4.26*4.28-XPR*YPR)
      YT=YPR*(140.2*4.28-133.1*XPR)/(4.26*4.28-XPR*YPR)
      ZT=ZR*(140.2*4.28-133.1*XPR)/(4.26*4.28-XPZYPR)
      RETURN
      END
      END$
```