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ANTHROPOMETRY AND
BIOMECHANICS OF
SELECTED POPULATIONS

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16. Abstract

This study reviews the limited literature and data available relative to anthropometry and biomechanical aspects of human factors, range of motion, strength,and kinematics of the body under different working conditions for selected U.S. civil populations. Particular emphasis is on the capability of the female, pregnant women, the handicapped or disabled (amputee, paraplegic, left-handed), obese, and the elderly to safely perform occupational tasks. Recommendations based upon evaluation of the literature are provided relative to future research needs and priorities.

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CONTENTS

I. CONCLUSIONS

The physically handicapped (amputees, paraplegics, and the left-handed), the female, elderly female, pregnant female, and the elderly male, as well as the obese male and female, represent significant sub-populations. Review of the literature relative to the anthropometry, strength, biomechanics, range-of-motion, and human factors of these groups clearly indicate that little attention has been focused on them in the past, and that basic information relative to their specialized requirements in the occupational environment is quite limited.

1. The Physically Handicapped

.Nearly one out of every four Americans has a disability of some type. Job demands in rehabilitation of the physically handicapped require assessment of range of motion, anthropometry, workspace human factors, strength capability, and biomechanics considerations.

.While a number of studies have been addressed to the handicapped wheelchair user, human factors requirements for the disabled have only received limited attention in the areas of access to public buildings and mass transit systems. Current air transport aircraft are not equipped nor arranged to accommodate the handicapped; 75% of the non-ambulatory handicapped were unable to reach an exit in time in a 1977 test. Concepts for accommodation of the handicapped and elderly in buses have been under serious study only during the past two years. Similarly the development of techniques to assess the driving capabilities of disabled persons, the evaluation and testing of adaptive devices, and design performance and safety guidelines requirements are only now being studied in an initial federal program. No work is being conducted in anthropometry, strength capabilities, range of motion,or biomechanics requirements of the disabled driver at the present time.

.Amputee ability to steer and brake commercial vehicles was reported in a 1968 study which found that-lower extremity amputees required a longer time to operate the brakes and above-the-knee amputees were generally unsuccessful in operating pedals with the impaired limb. This pioneering effort should be expanded to consider the occupants' workspace and control problems in current and future vehicles and also to consider female drivers.

.An excellent anthropometric study of male paraplegics/quadriplegics has been undertaken at the University of Melbourne, Australia in 1973-75,due to concern that the guadraplegic population could not be employed at meaningful occupations. Range of motion as well as biomechanics with reference to the wheelchair was also studied. However, it should be determined to what extent these data may apply to American males. There appears to be complete lack of information on female paraplegics/quadriplegics.

.While not generally considered "Handicapped," some 22 million left-handed individuals in the U.S. are attempting to adapt to various occupational tasks designed for right-handed individuals. Review of the literature shows that the left-handed individual has been virtually ignored in most human engineering design handbooks.

2. The Female Worker

.There has been a recent shift of millions of women into the labor force, increasing by 1.6 million alone in 1976. Women make up two-fifths of the entire labor force and it is estimated that nearly 50% of the U.S. female population is either employed or seeking work. However, although the female represents about 52% of the current U.S. population, she is grossly under-represented in studies of biomechanical and human factors aspects of the occupational environment and very little attention has been given to"women-machine" problems.

The strength literature for females is not extensive. Where comparative studies have been conducted, most often young college women make up the female subject pool. Even in specific areas where good studies have been conducted, such as the grasping reach of women, the subjects have been young college women. Such subjects cannot be considered as representative of the general female populations, and often are not representative of particular occupational requirements. A large proportion of the published studies of female industrial workers has been conducted in foreign countries. Although females operate all types of vehicles requiring seated pedal operation, almost all studies of seated forces applied to a pedal have utilized male subjects. No published data have been located for push forces for the female standing subject. There is a general lack of biomechanical data relative to the female, most studies having been conducted with male subjects.

.Although there appears to be no comparable civilian study, one study of military women employed in maintenance, electronics, and civil engineering areas found a significant number of problems relative to adapting females to tools, equipment, clothing, and workspace designed primarily for males. A review of female anthropometry shows that while there have been two recent comprehensive military studies of females, the most representative civil data available is the HEW Public Health Examination Survey report of 1965. However, this included only 12 linear measurements and six additional measures (compared to the 137-151 meausres routinely obtained in military survey). Thus quite limited anthropometry on the U.S. Civil female is available. An example of the problem manufacturers have with the lack of adequate dimensional information is provided by one chain in the garment industry alone,which estimated economic losses of $200,000 in 1976 due to incorrect sizing.

3. The Elderly Female

There have been almost no biomechanical, range-of-motion, strength, or human factors studies of the elderly female. Most anthropological studies of the elderly female have been conducted outside the U.S.,with the HEW Health Examination Survey providing 18 measures for 378 females between age 65-79. Other than these limited data, further published anthropometry for the U.S. elderly female is not available.

4. The Pregnant Female

.The pregnant female encounters numerous occupational problems, whether she is driving a car, sitting at a desk, or working at a bench. Recently limited attention has been given to some of these problems, with a 1976 report to NIOSH by the American College of Obstetricians and Gynecologists addressing some health and work environment questions. Independent posture/workbench (Chaffin 1975) and lifting load (Garg, 1976) studies have also contributed to our limited knowledge. No anthropometry, range of motion, or biomechanics studies of the pregnant female were found, and strength and human factors considerations appear to be limited to the several noted.

5. Elderly Males

·Elderly males have seldom been studied as a population. Most male anthropometry,especially military studies, has been conducted on younger age ranges. The most generally applicable data for the civilian elderly male is that taken on 265 males from age 65 to 74, and 72 males from age 75-79, for a total of only 18 measurements, in the HEW Health Examination Survey of 1959-1962, a population of 16-19 years ago. A more recent study by the author did utilize some male and female subjects to age 75, for neck range of motion, strength, and 48 anthropometry measures,but these data are unpublished. Biomechanics, range of motion, and strength studies involving the elderly are extremely limited.

6. The Obese

There appears to be no comparable studies of the biomechanics, anthropometry, strength, range-of-motion, or human factors considerations of the obese, relative to occupational environments.

II. OBJECTIVES

The purpose of this study was to conduct the following tasks:

1. Review of the current state-of-the-art which may be applicable to the occupational setting.

2. Determine what currently available data are directly applicable to the occupational safety setting.

3. Identify major research gaps which must be filled by various levels of research effort specific to the occupational safety setting.

4. Prioritize the research gaps found, if any.

5. Include, as an appendix to the report, a comprehensive list of applicable references.

III. METHODS

A thorough search of the literature was conducted to identify pertinent references. This was initiated by reviewing studies previously conducted by HSRI with regard to anthropometry, strength, body kinematics, biomechanics, range of motion. The author's files, consisting of several thousand publications in these areas, were also reviewed for published and unpublished work, as well as the holdings of the University of Michigan Library System.

These materials were supplemented by computer searches. An off-line bibliographic citation list was generated by a MEDLARS II National Library of Medicine National interactive retrieval service. Among the data bases were BIOSIS (biological sciences), SCISEARCH (biological and applied science), ISMEC (mechanical engineering and engineering management), NTIS (government research), COMPENDEX (engineering), FOUNDATION GRANTS INDEX (grant records), and SOCIAL SCISEARCH (social sciences) back to the years for which they came on-line in the computerized systems.

In addition, the proceedings of various societies were reviewed in the areas of human factors and ergonomics, physical anthropology, physical medicine and rehabilitation, biomechanics, biomedicine, bioengineering, gerontology, psychology, industrial and operations engineering, and physiology. Of particular pertinence were the Proceedings of the 6th Congress, International Ergomonics Association (1976), and various Communications, Danish National Association for Infantile Paralysis. One document, a list of literature, Anatomy for Planners I, issued by the National Swedish Institute for Building Research (1965), was most comprehensive, although now outdated.

Finally, when it became apparent that the literature in these areas as related to the selected populations was very limited, personal contacts were made with major investigators in the various related fields, and some as yet unpublished or obscure but pertinent materials were obtained. References resulting from these searches are provided in Appendices A-E.

IV. RESULTS AND DISCUSSION

1. Physically Handicapped or Disabled

Disability is the general term used by HEW to describe any temporary or long-term reduction of a person's activity as a result of an acute or chronic condition. Physical impairments may include visual, hearing, paralysis, absence of body segments, or impairments of various body functions.

Data reported by the HEW Health Interview Survey during the two-year period, July 1959 through June 1961, showed that there were 28,167,000 impairments in the U.S. civilian noninstitutional population (Gleeson, 1964). By 1971 there were an estimated 51.1 million impaired persons in the U.S. population (Wilder and Pearson, 1973), indicating that 23% or nearly 1 out of every 4 Americans has a disability of some type. Among the 12.5 million impairments due to injury the most frequently reported type consisted of a back injury (3.1 million individuals), followed by impairment of the lower extremity or hip (2.7 million). In 1971 62 individuals in every 1000 had an impairment due to injury.

A number of studies related to the handicapped have been conducted over the past two decades by the Testing and Observation Institute of the Danish National Association for Infantile Paralysis, located in Hellerup, Denmark. Many of the handicapped studies noted in this section are from this Institute. For example, Paulsen (1966) has evaluated job demands in rehabilitation of the physically handicapped. Among the factors analyzed are locomotion, working positions, body movements, muscular forces during work, and weights lifted. Asmussen (1965) had earlier assessed correlations between such variables as muscle strength and other physiological functions by age and sex.

An ergonomics approach to wheelchair design was investigated in several studies. Platts, at the Loughborough University of Technology (England), surveyed users'needs (1974). Engel and Hildebrandt of the Institut jur arbeitphysiologic und Rehabilitatimsforschung der Universitat Marburg/Lund, West Germany, have reported extensive studies of technical, biomechanical, and physiological aspects (1974). Additional studies which relate to the human factors design and biomechanics of wheelchairs for the disabled include Hiscock (1964); MacKeith (1974); Perizer et al. (1964); Roos (1964); Walker (1964); Bergstrom (1965); Bulletin of Prosthetics Research, (1965); Peizer (1965); Nichols et al. (1966); Lee (1967); Kemenetz (1969); Peizer and Wright (1969); Lipskin (1970); and Newsom et al. (1972). Space requirements have been considered by Floyd. et al (1966), particular needs of the quadriplegic and paraplegic (Edberg, 1965), physiological aspects of wheelchair operation (Hildebrandt et al., 1970), and as related to human factors of the handicapped wheelchair user in buildings (Leschly et al., 1959; 1960; U.S. Department of Housing and Urban Development, 1971).

Earlier this year investigators at the Civil Aeromedical Institute of the Federal Aviation Administration published a study on the emergency escape of handicapped air travelers (Blethrow et al., p. 77). Current air transport aircraft are not equipped or arranged to effectively accommodate the seriously handicapped occupant. Passenger movement of 1 ft/s has been found minimal for successful evacuation, but three-quarters of the non-ambulatory handicapped were not able to reach an exit in that time. This study recommended a number of human factors considerations, including increasing aisle width to accommodate wheelchairs, providing support handles, passenger information cards printed in Braille (blind), audible markers at exits and lavatories, and stabilizing ropes on inflated egress slides. They suggested that non-ambulatory passengers could be most effectively seated in a group in the cabin away from other evacuees, so that they would not impede escape. Besides a description of performance tests conducted, this study also provides a listing of case histories of handicapped involved in aircraft incidents or accidents. The handicapped subjects tested included one amputee, one obese individual, one blind individual,five cases of paraplegia,and eight individuals with mental deficiencies.

This study was instrumental in determining new air carrier requirements related to handicapped passengers. In April 1977, Parts 121 and 135 of the Federal Aviation Regulations were amended ("Air Transportation of Handicapped Persons who may need Evacuation Assistance," Federal Register, 1977). Seating requirements were not imposed, but a disabled passenger can not be refused transportation, and a number of allowances were made, such as exempting a person who cannot sit erect for a medical reason from the requirement that the back of his or her seat be upright for takeoff and landing.

Human factors requirements for the disabled have received increasing although still limited attention, particularly in areas of access to public buildings and mass transit systems. These aspects have a direct relationship to occupational requirements.

The Urban Transportation Act of 1970, the Federal Highway Act of 1973, and the National Mass Transportation Act of 1974 all contained various provisions for assistance to the elderly and handicapped. It is of interest that over 30 states had enacted laws related to accessibility prior to 1968, and many local communities had provided various transportation access requirements for the handicapped. An outline of pertinent legislation is summarized in Black and Mateyka (1976).

Human factors accommodation of the handicapped (and elderly) was a primary design goal of the nine advanced prototype buses constructed as part of the Department of Transportation, Urban Mass Transportation Administration (UMTA) transbus program. Three concepts for accommodating an individual in a wheel-chair on a full-sized transit bus have been reported by Black of Rohr Industries, and Mateyka of Booz, Allen Applied Research (1976). Among results reported was that wheelchair access is feasible for a bus with a wide front door and a low floor, a ramp stored under the bus floor being a preferred device. They found that step heights should not exceed 8 inches(20 cm) and step edges should be marked in contrasting colors (1st step height on current buses is about 14 inches (36 cm) high).

In recent years there has been increased concern with the requirements and capabilities of the disabled driver, and there have been studies conducted by the manufacturers, universities, and the government in this regard. Often human factors has been poor, as shown by the Veterans Administration finding in New York that only 3 of 12 commercially available systems of hand control of automobiles met safety and durability standards (Paul, 1964). Goodwill (1974) had outlined the status as of that time in the U.K. for disabled drivers.

A major attempt to develop driving aids and systems for the disabled driver is presently underway at the University of Michigan, sponsored by the Rehabilitation Services Administration (RSA) of the Office of Human Development, U.S. Department of Health, Education and Welfare. A Rehabilitation Engineering Center, funded for $300,000 for the first year of a five-year program, in cooperation with the Rehabilitation Institute of Detroit, is focusing on a program of medical research concentrating on driver disabilities and assessment. Among areas to be investigated are the development of techniques to assess the driving capabilities of disabled persons, the evaluation and testing of adaptive devices, and providing designers with performance and safety guidelines (U.S. Department of Health, Education and Welfare, 1977). Human factors studies planned include attention to control input characteristics and assessment of physical driving capability. To date no work has been initiated in anthropometry, strength, range of motion, or biomechanics of the disabled driver relative to this program.

(a) Amputees

In 1968 McFarland and colleagues at the Harvard School of Public Health, supported by the Vocational Rehabilitation Administration, Insurance Institute for Highway Safety, and General Motors Corportation, evaluated the ability of amputees to operate highway transport equipment. At that time it was estimated from the 1957-58 U.S. National Health Survey that 24 million Americans suffered from some form of physical impairment and that 13 million of them involved some limitation of motion. Further, of 3 million seriously disabled persons, some 1 million drove with some type of special hand or foot controls. However, the approach that was taken in this study consisted primarily of a survey of the literature and evaluation of the driving experience of amputees. Particular attention was given to state licensing procedures for physically handicapped drivers and their accident experiences, and the possible relationship between physical handicap and motor vehicle accidents. A major concern for this problem was that relatively large numbers of the potential workforce might be unfairly deprived of opportunities for employment. The rules of the Interstate Commerce Commission did not allow operators with amputations to drive in interstate commerce, in any public conveyance, in large or small trucks, or in buses or passenger conveyances for profit.

To study physical components of steering and braking of commercial vehicles, 100 subjects, 60 of whom were amputees, were tested in a vehicle simulator. Anthropometric measures were taken on these subjects for 80 different measurements relating to body size, structure, and composition on each of 30 upper extremity amputees and 29 lower extremity amputees. Grip strength was also taken. It was found that the amputee group did not generally differ anthropometrically, although the sample pool was small. Because chest circumference and left calf circumference were significantly greater for the lower amputees, it was speculated that the cause might be the extra muscular effort or respiratory demands of walking with a prothesis. The experimental steering performance tests indicated that amputees did as well or better than non-impaired, non-commercial drivers. The brake pedal tests indicated that the lower extremity amputees required a longer time to operate the brakes. Above-the-knee amputees were generally unsuccessful in using the impaired limb to operate pedals.

There have been numerous studies of prothestics, but in such cases anthropometry is usually taken only relative to individual fitting requirements. Isherwood (1976), for example, has devised prothesis simulators consisting of a set of compressible bags using a compressible foam which is individually constructed on the stump of the patient. In most cases equipment manufacturers tailor the handicapped aids to the specific individual. Similarly emphasis on strength appears to be concerned with preparation of the individual to resume ambulatory and weight bearing functions.

Working conditions with different types of disability were examined by McEiven (1973) in an Australian study. He reported that individuals with retarded impairments tended to be found in jobs where noise levels and demands for speed, exactness and team work were relatively high, while individuals with psychotic types of impairments favored jobs where these factors were low. It was hypothesized that retards were better able to cope with stress before their performance deteriorated, due to a lower arousal level.

(b) Paraplegics/Quadriplegics

Quadriplegics comprise a readily identifiable sub-group of the handicapped population. The most recent published work is an anthropometric survey of quadriplegics conducted by Samuel and Young at the Department of Mechanical Engineering, The University of Melbourne, Australia (1975). This study was undertaken during 1973-75, when it was found that the quadriplegic population could not be employed at any other than the most menial of tasks, and information on the limitation and requirements of quadriplegics was insufficient. It probably represents the first systematic attempt to collect anthropometric data for the physically handicapped adult male population.

Both static and dynamic anthropometry were taken, as well as biomechanics including joint range of motion and grasping strength. Anthropometry was taken in and about the wheelchair, but might have application to any seated workspace environment, since seat, buttock, and shoulder reference points were taken, and measurements related to these rather than from fixed reference points. Since quadriplegics have insufficient trunk stability, most of the 53 adult males in this population measured (data was complete for only 38) could not sit in an erect position. Thus standard techniques were modified. A basic aim of this study was to compare the anthropometry of the disabled to the non-disabled population. The authors concluded that these subjects, at least, were representative of the general population and found to be distributed normally in all measurements. (These findings are of interest to the author, who has recently measured a series of three female paraplegics (loss of motion of lower extremities), and findings suggest significant anthropometric differences (unpublished data, Snyder 1977).

Range of motion (dynamic anthropometry) was measured for maximum forward and sideways reach for both right and left arms, and for both a restrained and unrestrained upper torso (in the wheelchair). In addition, an objective measure of horizontal work space capabilities was attained with the subject and wheelchair placed against the measuring board and horizontal board, and single arm (comfortable reach), single arm (maximum reach), two hands together (rotating arc), and single arm rotation (arc) reach envelopes measured.

Biomechanical aspects of upper limb joint movements, including head and neck motion, were also measured in this study. Objectives were to show how joint movement angles are related to envelopes of arm movement, to determine the extent of impairment of joint movement and relate it to joint movement of the unimpaired person, and to determine if any poorly functioning joints could benefit from mechanical aids.

The arm movement envelope data were subdivided into four classification sub-groups of (C_{4-5}), (C_5-C_{5-6}), (C_6-C_{6-7}) and (C_7). The authors found that within the second and third sub-groups standard deviations on reach were similar to those of the unimpaired population compared to. While mean head and neck rotations were reported to be similar to the unimpaired population, deviations from the mean were found to be slightly greater. Only the C_7 group of quadriplegics had any measurable finger and thumb movements. Wrist, shoulder, and elbow motion was found to increase in restriction with the level of injury.

Task performance of this quadriplegic population was determined to be considerably below that of the unimpaired population. For the two primary sub-groups of (C_5-C_{5-6}) and (C_6-C_{6-7}) individuals, performance time for the simple pick-up-transport task required about three times the D.M.T. standard. Quadriplegics also were found to perform poorly with pegboard location tasks and it was recommended that work tasks (or occupation) such as push-button telephone or typing be avoided. Performance was also found to be affected by rod size and for grasping controls (optimum performance) knob diameters "should not be less than 10 mm" (p. 282). The authors concluded that the Australian wheelchairs used by the Victoria quadriplegics are similar in size and geometry to those in the U.S., and suggested that the measurements obtained would therefore be applicable to U.S. wheel-chair bound quadriplegics. While the Samuel and Young Australian study is considered to be an excellent comprehensive study in anthropometry of the handicapped at this point, it has a number of limitations, including the lack of any data on female quadriplegics.

(c) Left-handedness

While left-handed persons are normally not considered "handicapped," it is estimated that there are some 22 million left-handed individuals in the U.S. Since these individuals comprise only 10% of the population they have had little study relative to adapting to various occupational tasks, almost all of which are designed for right-handed individuals.

Like other handicapped groups such as the blind and hard-of-hearing, the left-handed individual has had to learn to adjust to the majority right-handed world. Suddon and Link (1959) have found, however, that left-handers are better able to perform complex motor tasks with the right hand than right-handed individuals can with their left hand.

The left-handed individual has been virtually ignored in most human engineering design handbooks. One of the most recent, for example, Van Cott and Kinkade (1972) does not directly consider handedness. Illustrations and data provided are shown for right-handed individuals only, except for tables of maximal static hand forces exerted on a horizontal handgrip (after Hunsicker, 1957), which are provided for both the left and right hand. However, it is not stated whether these data include left-handed subjects. Design handbooks presently appear to suggest that the user use the same relationships for either hand until further experimentation is conducted (Murrell, 1965), or provide a notation that the data are for right-handers only (Chapanis and Grappes, 1968). Other handbooks simply do not address the problem (McCormick, 1957).

While Damon, Stoudt and McFarland (1967;1971) do index handedness, consideration is limited to three sentences dealing with factors influencing muscle strength: "Handedness: In the right-handed persons (roughly 90 per cent of all), the left hand averaged about 10 per cent weaker than the right (Hunsicker, 1955). Schochrin (1934) found the left leg also to be 10 per cent weaker. In general, the preferred side is the stronger" (p. 202). They also considered right versus left side in presenting factors influencing the range of joint motion, reporting Gillilands' (1921) finding that "there is normally so little variation that the two sides can be considered identical," and Salter and Darcus' (1953) conclusions that in arm rotation "group differences between left and right ranged from 0 to 5 degrees" (p. 189). Since this range of joint motion data is indexed under "handedness," it could be misinterpreted by the user.

Laveson and Meyer (1977) have addressed the problem of the left-handed handicap by developing a methodology capable of analyzing consumer products to determine the means by which they may be modified or adapted to left-hand use. They apply task analysis by determining the force-related components involved in the operation of the product. Thus elements of input, output, and control are analyzed by consideration of how the force is applied, how the force is utilized, and how the force is controlled. The analyses are then compared to determine similarities and differences. A product with identical analysis is determined to be usable by either hand in their system. If the analysis differs, then product modification or complete redesign is required. These authors applied their methodology to an electrically operated drill with a handle on the left side, a circular saw, and a serrated kitchen knife. These authors suggest that this technique can be adapted to a wide range of office, business, and industrial occupational tasks, but to date no further work has been published.

2. The Female

During the past decade there has been a shift of millions of women to employment outside the home. At the same time there has been a trend toward the expectation of equal employment opportunity, as well as new knowledge concerning environmental health hazards. The recent passage of the equal rights amendment to the Constitution, if ratified by the states, could have still further impact on increases in the female work force. It has been reported that in 1976 alone the female labor force increased by 1.6 million (or 200%

that of males for this same period) to a total of 39,255,000. Women make up a significant portion of the labor force when it is considered that two-fifths of the entire work force are women and that nearly 50% of the female population is either employed or seeking work. The military has also increased female personnel, the Air Force alone increasing females by 129% in the 5-year period prior to 1973, with plans to increase the 1973 number of females from 19,500 to over 44,500 by 1978 (Bobbitt, 1977).

An analysis of female workers in industry and by occupation has been compiled by Waldmas and McEddy (1974). Their findings indicate that about 60% of all employees in the service industry were women, with 60% in educational services, 75% in the medical-health industry, about 75% in personal services.

At least 50% of all employees in the manufacture of clothing and general merchandising are women.

Despite these statistics showing that women presently make up a significant portion of the U.S. total work force, and although the female represents about 52% of the present U.S. population, she is grossly underrepresented in studies of biomechanical and human factors aspects of the occupational environment.

There has been an increased awareness and interest in female anthropometric requirements in the industrial and work environments, but little such data exist relative to the civil female population. A 1965 Czechoslovakia anthropometric study by Šmid of 408 women in an industrial plant pointed out that women are now working in all fields and occupations where formerly only men were employed. In this regard it is important that the different physical and physiological makeups of women be taken into account in efficient industrial workspace design.

Although ergonomics and human engineering studies are concerned with "matching work to people" (Corlett, 1976), such studies have historically concentrated on the "man-machine problems" (Product Engineering, 1960). Examination of the literature reveals that this is literally true. As a result very little attention has been given to the "woman-machine" problems. This is quite evident, not only in the data provided in most standard human engineering texts when sources are revealed, but also in the illustrations provided in which male figures are shown. Female studies appear to be mainly confined to specialized reports such as Kroemer's work in human engineering of the keyboard (1972), office seating (1971), and industrial seating (1970). An excellent review of the principles of industrial seating has been provided by Kroemer's 1970 study, noting the interactions between work station design, body posture, and task performance. Anthropometric and biomechanical data with recommended dimensions are provided for work seats and benches, foot rests, office equipment, consoles, and machine stands. However, except for discussion of typist requirements, the data provided appears to be based upon male criteria; different sexual requirements are not indicated. Office and factory seating habits of British adults were found to be established in schools by Floyd and Ward (1967) in an English study.

In general it has been found that women are about 66% as strong as men, varying with different muscle groups (Damon et al.,1971). Female forearm flexors are only about 55% of men's strength, but this increases to about 80% for flexors and extensors of the hip, and flexors of the lower leg. While strength of a muscle per unit cross-section may be "virtually the same in both men and in women" (Hettinger, 1961), correcting for body size results in the conclusion that females have about 77% of the strength of males (Asmussen and Heebbill-Nielson, 1962). Hettinger (1961) also found that muscle training produces greater proportional strength increases for men than women. New approaches have been reported on male/female strength stressing by Snook (1977).

More recently, Laubach (1976) has conducted experiments to measure static muscular strength characteristics in comparison with previous data available for males. This study included 12 measures of static muscular strength, 22 body-size measures, and somatotypes of 31 female subjects. Results indicated that the "overall" total body strength of women as compared to men is about 63.5%, with a range of 35 to 86%. For the upper extremities, static strength of women was found to be 59.5% that of men, with a range of 44 to 79%. When strength of the lower extremities was compared, it was found to be 71.9% that of men, with a range of 57 to 86%. Female trunk strength was 63.8% that of males, with a range of 37 to 70%. Laubach also reported the dynamic strength characteristics, including lifting, lowering, pushing, and pulling tasks, of women to average 68.6% that found for males, with a range of 59 to 84%.

Grip strength data for women are important in proper design of length and configuration of the moment arms of various hand tools and hand caliper brakes. Even in such a common activity as riding a bicycle the forces required to stop by using the hand brake may be excessive for a given hand/wrist/forearm configuration, especially for a weak female. The effect of wrist and forearm position on grip strength has been discussed by Terrill and Purswell (1976), but no comparison data for female provided. Lamphiear and Montoge (1976) have studied the relationship of arm and grip strength measurements to various anthropometric measurements (height, biocromial diameter, arm girth and triceps skinfold) for both sexes over a wide age range, and proposed and index of strength.

Isometric strength for 25 different muscle groups has been compared for 360 Danish men aged 15 to 65 and 250 Danish women aged 15-55. Except for the

15-20 year olds, the average value for all women was found to be only 58-66% of that of men of corresponding age. Maximum muscle strength was reached sooner in women but decreased at an earlier age. Since a positive correlation between height and strength has been shown, corrections were applied to the female subjects and women's muscular strength was found to be no more than 70 to 80% of that of men of the same age (Asmussen and Heeboll-Nielsen, 1961;1962).

Isometric muscular strength has also been measured by Rohmert and Jenik (1971) in ten females between ages 17 and 24 years of age in various arm reach positions. Further strength measurements included maximum lifting strength of both arms, foot pressure exerted by the right leg from a sitting position, central push and pull of the arm, and adduction pull and abduction push of the arm within arm reach and from a standing position (1973). They found the mean strength difference between men and women to be about two-thirds, but note that there is a wide range of strength differences between men and women.

Ten college age women were also involved in a study of forces produced by maximum voluntary isometris muscle contraction (Williams and Stutzman, 1959). Tests were conducted on the knees, elbows, shoulders, and hips through the range of motion.

Static muscular strength of 31 female college subjects (mean age 20.7) for 12 measurements, including 22 body size measures, and somatotypes, have been reported by Laubach, and compared to male capabilities (1976). The subjects were apparently the same as used by Kennedy (1976) in his study of reach of women. Variables included shoulder flexion, elbow flexion, hip flexion, knee extension, trunk flexion, and grip strength. Strength data on 152 female Braniff International Airways, Inc., stewardesses for 4 strength tests and 13 body measurements have been reported by Reynolds and Allgood (1975). Strength tests involved a two-handed push (110 cm from floor), leg lift (25 cm from floor), back lift (50 cm from floor), and arm lift (100 cm from floor). However,the authors note that there are no comparable data in the literature and that "in general, the average airline stewardess does not appear to have the body build of the average American female" (p.3).

Matching a person's physical capabilities to a job's physical demands has become of increasing importance in consideration of affirmative action programs for women, the disabled,and the handicapped. This has resulted in a need to develop more objective pre-employment selection and employee placement tests relative to the necessity for improved occupational health and safety programs in industry. During the past nine years work has been conducted at the Human Performance and Safety Research Laboratory of the University of Michigan on the development of biomechanical strength models and physical job evaluation methodology (Chaffin, 1974; 1975; Chaffin and Baker, 1970; Chaffin and Park 1973; Garg and Chaffin, 1975; Herrin et al.,1974; Herrin et al.,1976; Chaffin and Herrin, 1976; Martin and Chaffin, 1972; Park and Chaffin, 1975).

Standardized pre-employment strength positions (arm, leg, torso) were evaluated for 443 males and 99 females in one study (Chaffin and Herrin, 1976). A lifting strength rating (LSR) (maximum load lifted divided by predicted maximum lifting capability) has been developed by Chaffin (1973) (Chaffin and Herrin, 1976), and evaluated. In one study 135 people in five plants of a large electronics manufacturing company were selected for evaluation of 38 jobs, and low-back pain tabulated. Findings indicated that jobs with high LSR values were higher than expected by medical and safety personnel. In an extended study, 411 males and females working on 103 jobs were evaluated and 25 incidents of low-back pain identified. Interestingly, females were found to show a higher job-related low-back pain incidence rate at the 0.5-0.8 job lifting strength rating than males, although slightly less at 0.2-0.5, and significantly less at 0-.2 ratings. This work clearly indicates that the differing physical lifting capabilities between males and females must be taken into consideration in pre-employment job matching.

Biomechanical strength models have been reviewed by Chaffin (1976). He notes that among the uses the model has been put to in industry is to identify the strength requirements of various jobs to predict the proportion of various working populations (young, old, women, handicapped, etc.) who could perform the various tasks comprising over 500 jobs in one large corporations plants.

Ayoub et al. (1976) has followed up Chaffin's (1969) recommendations in an experiment utilizing females as well as males, including some industrial worker subjects, to establish the maximum acceptable weight of lift for three heights of lifting tasks. The results indicated that the maximum acceptable weights of lift were lower for females, being 49% to 62% of the maximum acceptable lift for the males.

In an experiment with 4 males and 4 females Jorgensen and Poulsen (1974) found the maximum lifting frequency (maximum load which could be lifted from floor to table) of females to be approximately 0.7 of that of males at the same relative burden. They concluded this difference was due to difference in the capacity of the oxygen transporting system in the two sexes.

Twenty-nine women textile workers work loads were evaluated in a Swiss study (Nemecek, 1976) which found that fatigue, shoulder and wrist pains, and total work performance seem to be related to degree of training and adaptation. However the data for determining work pulse as a threshold value for continuous work for women have not yet been adequately determined according to Nemecek.

In 1971 Rohmert and Jenik studied 10 German women, finding an average force of mean maximal length strength of 1010 neutons, compared to 1510 neutons found in Muller's 1936 study of two German women.

Brown (1971) has made an extensive review of the literature and summarized back injury and lifting studies as an industrial hazard in a publication for the Labour Safety Council of Ontario.

Studies in the United Kingdom have shown that the highest incidence of back injuries occurs in employees between 31 and 40 years of age (Brown, 1972) with 8.7% involving females, yet by age 41 the incidence increases to 14.1% and between 50-60 is 14.4% (p.5).

A study by Snook and Ciriello (1974) included 15 female industrial workers and 16 housewives who performed a number of work tasks. These included 3 lowering, 3 lifting, 4 pushing, 1 pulling, 1 walking, and 6 carrying tasks. Comparison with a previous study on males showed that the average weight handled by industrial women was significantly lower than that of men, but significantly greater than weights handled by housewives.

Maximum power output during the performance of a standing broad jump of two feet from a force platform and stair climbing has been studied by Davies (1971), who calculated male mean power output values of 5.23 hp and 3.15 hp for women.

The range of motion varies considerably between individuals, depending upon age, sex, physical condition, and other factors. Joint mobility decreases only slightly in healthy people between 20 and 60 years of age. However, beyond age 45 the incidence of arthritis increases so markedly that both male and female elderly populations will have significantly decreased average joint mobility (Smyth et al, 1959). It has been found that females exceed males in the range of movement at all joints but the knee (Hertzberg, 1958). The widest range of joint movement is found in thinner males and females (Barter et al.,1957).

Physical exercise may increase the range of motion of a joint, but excessive exercise can reduce motion if the individual becomes "muscle bound." The author has observed these problems in weight lifters who have tried out for competitive swimming.

Inadequate sitting and standing postures have been found to result in pains in muscle and connective tissues of tendons, joint capsules, and ligaments, and can become the symptoms of chronic diseases attributed to rheumatic disorders. Grandjean et al. (1968) studied female department store shopclerks and officeworkers (Grandjean and Burandt, 1962), and have summarized orthopedic principles for a tiltable seat shell appropriate for work necessitating alternating leaning forward and reclining seated postures (Grandjean and Hiinting, 1977) and of other seating work places (1973).

The lack of biomechanical abilities has been pointed out by Damon (1971), "Biomechanical abilities have been studied chiefly among small groups of white males, American or European. Comparable data for females, other racial groups, or for specific ages or occupations are few or nonexistent" (p. 187).

Although females operate all types of motor vehicles and aircraft requiring design of efficient seated pedal operation, almost all studies of seated forces applied to a pedal (fixed or pivoted) have utilized male subjects. Kroemer notes (1972, p.2) that Miller (1936) "was the first and apparently, until 1971, the only researcher to publish such strength data of (two) women in addition to the scores achieved by one man."

In the area of push forces for standing subjects, no published data for women has been located, although there are many such studies for push and pull of males.

An extensive review of the literature of flexibility studies has been published by Holland (1968), and for the measurement of joint motion by Moore (1949).

Female flexibility is often assessed in tests for physical fitness by the toe touch, on the assumption that flexibility and mobility of the body is of a general nature. However, Harris (1969) concluded that there is no evidence that flexibility exists as a single general characteristic of the human body. In this study 147 college-aged women were examined for 53 variables, including 38 joint motion, 13 composite, and 2 anthropometric measures.

The grasping reach of women (and men) in the form of vertical planes at 15° intervals from a vertical through Seat Reference Point has recently been extensively studied in a doctoral dissertation by Kennedy (1976). Tabular data describing vertical planes at 15° intervals for women are presented along with graphic data. In this study, which duplicated a study of males the author reported in 1964, 12 anthropometric measures were made on 30 female college students and Air Force personnel. Despite the limited sample tested, this is the first attempt to describe the complete 3-dimensional 5th, 50th, and 95th percentile grouping reach envelopes for the seated female and to describe for design location for critical hand-operated controls in machine and vehicle operating compartments.

A general review of industrial machine guarding for the worker has been published by Roozbazor (1977) and some data pertinent to the female are provided. Recently Adams et al.(1976) have examined human factors in grain harvesting equipment design, Sjoflot (1976) Norwegian farm tractors, Alioth et al.(1976) work groups in Swiss Supermarket warehouses. Fechter (1976) has described human factors research at the National Bureau of Standards as illustrated by a study of cooking ranges.

Application of ergonomics to the kitchen environment has been studied especially by the English. Concerns have ranged from layout and overall special requirements to working surfaces. While intended for domestic environments, some of the findings might also apply to restaurant kitchens and other work environments where a female worker must stand or sit. Dudgeon

(1963) measured 56 adult British women aged 18 to 40 years, for anthropometric dimensions relative to the heights at which each preferred a work surface to be set in performing selected domestic kitchen tasks. Saville (1967) measured the physiological responses of the subjects to the tasks. Ward and Kirk (1970) have further studied the relationship between anthropometric measurements and kitchen working heights. Their conclusions showed that there were significant correlations between elbow height and preferred standing and seated work surface heights, not only between subjects of different stature, but for the different activities performed.

The problems in the Army of adapting women to equipment, clothing, and workspace designed primarily for males, and necessary changes to the Design Handbooks, has been recently outlined by Glumm (1976). Another recent study addressed the adequacy of the tools and equipment for Air Force women now employed in maintenance, electronics, and civil engineering (Bolalek et al. 1975), finding a significant number of inadequacies, which undoubtably would apply to civilian female workers in these fields as well.

Anthropometric standards for working women were proposed by Bayer and Gray in a 1934 study of 100 working women from 20 to 60 years of age of Northwest European stock. However, a number of selective requirements were utilized, including healthy subjects and weight within 15% of predicted. A review of subsequent U.S. civil anthropometric studies is provided in pp. 25-27).*

In an English study 5000 civilian women aged 18 to 70 were studied to provide a range of measurements for clothing manufacturers and a sizing system based upon stature, hip girth, and bust girth (Kemsby, 1957).

*Since this study is confined to the civil population, a number of excellent military studies have not been included because they were conducted on other specialized segments of the population. However, several recent studies of military females have been completed. A 1977 report on U.S. Army women provides data on 128 conventional body size dimensions, 14 workspace dimensions, and 9 static strength measurements (Laubach et al.). A number of these measurements had not been previously reported for women, either military or civilian. In addition, 137 anthropometric dimensions have been reported as a result of a 1968 survey of Air Force women (Clauser et al., 1970).

A comparison of the segment volumes and link lengths of 12 college females was made with Dempsters' (1955) male study and the most significant differences were found in the calf, thigh, and head-torso (Kjeldsen, 1972).

A review of civilian anthropometric studies conducted in Czechoslovakia during the past three decades provides mean height, weight, and chest circumferences for women over 18 years (Prokovec, 1969). However, body size data on women from Czechoslovakia, England and other countries may not be applicable to the U.S. female.

Female air carrier flight attendants have been measured in a study of 423 women for 72 standard and functional anthropometric measures. (Snow et al., 1975). This study was intended to provide improved criteria for workspace design and emergency equipment usage for stewardesses. The relatively young age range of these women and physical characteristics in job selection, however, make this a specialized female population probably not representative of the U.S. female as a whole.

A study of 180 civilian males and females, aged 18-74 years, chosen by sex, age group, and stature to represent the U.S. population was conducted by Snyder et al. (1975). Included in this work was head and neck anthropometry, sagittal plane range of motion of the head and neck, determination of the response of head and neck muscles to low levels of acceleration, and measurement of voluntary isometric strength of neck flexor and extensor muscles. Elderly females were included in this study.

The female hand is important to the proper design of controls and equipment in industrial and other work environments. The female hand has been extensively studied by Garrett (1971) for anthropometry and biomechanical characteristics. Included is standard and "relaxed" anthropometry of the hand, bare and pressure-gloved performance, and the ability to retain grips on selected handles under high dynamic loads. Biomechanical measures included maximum rotation (supination and pronation), and a large number of hand clearance and grip dimensions. However, the greatest limitation of this excellent study may be in the question of how representative of the U.S. female the young college students selected may be.

A number of studies have been directed towards energy requirements and the physical work capacity of women; however, these are considered to be outside the scope of this study. Wardle (1977), for example, has found that women can work under conditions requiring strenuous (heavy) work.

(a) <u>Elderly Females</u>

The elderly (65 years of age or older) represent an increasing proportion of the U.S. population. In 1974, 21,815,000 males and females, or 10.3% of the total population were 65 or over. By 1980 it is projected by the Bureau of the Census that 24,523,000 Americans will be 65 or over. In 1974 58.9% (12,849,000) of those over 65 were female; in 1980 this is projected to increase to 59.6% (14,609,000) female.

The aging process greatly affects not only joint range of motion, strength and other biomechanical factors, but also body size and human factors considerations. There is an increased incidence of arthritis and other crippling diseases which restrict joint range of motion. Posture, reach, motion, as well as performance in most areas is decreased. A slower reaction time and decrement in highly skilled work also accompanies advanced age. Activities or work requiring exposure to falls present a considerably greater risk of injury than to younger individuals.

Several studies of the anthropometry of elderly females have been conducted, but for the most part, these have been outside the U.S. In 1960, Roberts published 30 measurements on 78 women aged 56-99 years to provide data for use in the design of English "flats," finding that this was indeed a specialized population. Rogers found that body size was smaller than that of the younger British female population, with height averaging 3 to 4 inches less. In measurements of "comfortable reach" it was concluded that an important variable was the reduction in reaching ability due to arthritic and joint range limitations. A third difference was the relative weakness of muscular effort. The average dynamometer grip strength of the preferred hand of 14 kg was found to be significantly lower, with some individuals with arthritic hands who could exert a grip strength of only 3 or 4 kg (Roberts, 1960).

This was followed in 1964 by a study of 100 elderly women in the Birmingham (England) area (Jones, Lawton, and Myles, 1964). Both of these studies were proposed to provide domestic architectural design requirements. Ward and Kirk (1967) have compared these two populations relative to body dimensions and found them to be substantially the same.

During the period October 1971 through June 1972 five measurements (forward reach, elbow height, vertical reach, stature, and weight) were taken on 7,187 British women (between the ages of 18 and 80 years) (Thompson, et al., 1972). These data were intended to update the previous survey of British women of the 1940's, and provide information felt particularly needed for the "design of work places, fittings and equipment in the home" (p.2). This study included 124 women between ages 66-80 years of age (71, 66 and 70 years; 31, 71 to 75 years; 22, 76 to 80 years). However, in order to get a large national sample, some 64 organizations cooperated in data collection, with the information "gathered by members of the organizations and by students as part of their teaching and training programmes...and the data were obtained by hundreds of measures all over the country" (p. 2). This technique, plus the taking of all measurements, including weight, with subject fully clothed, makes these data difficult to compare and introduces considerable potential for measurement error.

There are several major studies of the anthropometry of U.S. civilian women, but relatively little data on the older female. For example, in the most recent anthropometry study of U.S. women (in the Army) only 3 individuals were over age 50, and only 12 between 45 and 50 years, of a total sample of 1,331, and mean age was 23.1 years (Laubach et al, 1977, p. 23). In contrast, the mean age of women in the U.S. population is 28.8 years (Bureau of Census, 1976, P. 25). For the 7 female U.S. military female anthropometry studies listed by McFarland et al obtained between 1943-1952, mean age ranged from 18 to 31 years (1971, p. 60-61), and for 9 U.S. civilian female studies between 1928-1957, mean age ranged of 17 to 45 years (1971, p. 60-61).

In 1941, O'Brien and Shelton described 50 measurements on some 15,000 civilian women in a U.S. Department of Agriculture WPA Project. Commercial Standard CS 214-58 of the U.S. Department of Commerce, promulgated on 24 February 1958, was based upon work between January 1949 and April 1952. This is intended to provide a means of sizing women's clothes for 45 measurements. However, it is significant to note that these data are now greatly outdated as indicated by one major U.S. clothing store's loss of over $200,000 alone during the past year due to clothing returns (wrong sizes). (personal communication, 1977).

The Public Health Examination Survey included anthropometric measurements on 6,672 adults of a probability sample of 7,710 persons selected to represent the 111 million adults in the U.S. civilian noninstitutional population aged 18 to 79 years. These data were taken from October 1959 through December 1962, although not reported until 1965 (Stoudt et al.). This population included 564 individuals (265 male and 299 females) from age 65 to 74, and 142 individuals (72 male and 79 females) from age 75 to 79. This provides the most current population sample presently available for U.S. elderly and consists of the largest sample of U.S. elderly females. Twelve linear measurements were taken. These included stature, weight, sitting height (erect), sitting height (normal), Knee height, popliteal height, elbow rest height, thigh clearance, buttock-knee length, buttock-popliteal length, elbow-elbow breadth, and seat breadth. Six additional measurements were also taken, including right arm skin fold, infra-scapular skin fold, right arm chest and waist girths, and biocromial diameter.

Some efforts to provide design information for special populations such as the elderly (as well as handicapped and wheel chair users) must be carefully evaluated, especially when the reference does not identify the source or specify the techniques used. In such cases, even though information provided purports to apply to specialized populations, it may be misleading. An example is the review by Faulkner (1975) of Humanscale 1/2/3, a design kit, who recommends that it be burned due to "the questionable nature of the data."

(b) Pregnant Females

There are nearly 4 million births each year in the United States. During the term of pregnancy the female becomes part of the minority population with special problems and handicaps. With the increase in abdominal protuberance, pregnant females become susceptible to unusual occupational hazards and problems.

Recognition of the need for guidelines on pregnancy and potential hazards of various work environments was formalized by a recent study conducted for NIOSH (under contract no. 210-76-0159) in 1976 by the American College of Obstetricians and Gynecologists (ACOG, 1976). The primary objective of this work was to prepare guidelines to assist the practicing obstetrician in making judgments necessary to advise pregnant workers in matters of health. A secondary purpose of this study was to collect a bibliography of pertinent reports related to the effect of work environments on the health of the mother and fetus.

Some biomechanical (ergonomic/physical energy) hazards for the pregnant women have been addressed to some extent (2 pages) in this obstetrical study.

Although excellent recommendations relative to lifting and load carrying, seating and environmental problems specific to the expectant female are provided, they are based upon a limited number of references, and only general considerations are addressed.

It is indicated that the physical exertion tolerance of the pregnant woman in lifting, climbing, or pulling strength tasks will vary greatly, depending upon variations in physical fitness and strength, the load handled, and the work environment (Buttrey, 1977). During pregnancy there may be non-specific symptoms such as backache, headache, or nausea, which can be aggravated in some work assignments (Diddle, 1970). The risk of falling appears to be greater during pregnancy, and wearing of shoes with adequate support and low heels has been recommended to lessen the shift of the weight bearing angle (ACOG, 1976).

The ACOG report notes that the amount of weight to be lifted by females has for the most part been discarded by state regulatory bodies, indicating that it is not lawful to set a limit on what a pregnant (or non-pregnant) woman should lift. A load which can be lifted readily by a woman should not provide too great a stress while she is pregnant. In some cases the protruding abdomen present in the last trimester may cause an individual difficulty in lifting loads in front of her body. This has also been one point in question in recent litigation and labor negotiations regarding how long pregnant air carrier flight attendants can work.

An important point is that the change in posture necessary for the pregnant women to lift the load in front creates unusual stresses on the lumbar spine. Often the load which could be lifted before pregnancy must be reduced if the woman is not to be overstressed. The amount of load reduction can be calculated based on metabolic considerations but the amount of energy expended to lift a load should be the same, before and during pregnancy. A load that was at a maximum level prior to pregnancy should be reduced from 20 to 25% during late pregnancy. (Garg, 1976; Seitchik, 1967).

Further considerations relative to the biomechanics of the pregnant women also relate to the changes in body structures, particularly the protrusion of the abdomen and changes in the abdominal musculature and pelvic ligaments. Body balance may often be affected. It becomes more awkward for women to perform certain body movements after the 20th to 24th week of gestation, and women are advised to avoid work situations involving a strained posture or requiring a good sense of balance. Climbing ladders becomes more difficult and should be avoided. Since the abdominal musculature and ligamental attachments may be more vulnerable to unusual loading, twisting, or bending motions, or slippage on unstable work surfaces, pregnant women are also advised to avoid working in environments where protection against slips and falls is inadequate. (Kane et al., 1967; ACOG, 1976).

These structural changes in the pregnant female also require particular attention to adequate support in the seated posture. A low backrest, supporting both the lumbar and sacral area of the pelvis, is of special importance. It is also necessary that the seat be wide enough to allow the pregnant worker's being seated with both legs in a semiabducted and supported position. Often seat pressure by the seat pan on the area above the knee may be of painful distraction and a small footrest has been recommended to alleviate such suprapopliteal pressure.

Particular attention should be paid to the work surface height for the pregnant woman. The pregnant woman should be allowed to perform work tasks either seated or standing. Frequent changes in posture may be necessary in the last trimester. Chaffin (1975) has suggested that a high stool be matched to a relatively high workbench, to allow no change in the work surface height when the pregnant woman chooses to alternate seated and standing work positions. It is further noted, however, that this type of work place requires footrest support when in the seated position, to avoid compromise of venous blood return from the legs. (ACOG, 1976).

Concern with the pregnant occupant in air and ground vehicle crash impacts (Rubovits, 1964) has resulted in a series of studies (Snyder et al., 1966; 1967; 1968; Crosby et al., 1968; Crosby and Costiloe, 1971) to determine impact effects upon the pregnant female and fetus. One result has been the attempt to design improved restraint protection. A net-type restraint system developed by researchers at Wayne State University was shown to protect pregnant sub-human primates in simulated frontal barrier crashes from 15 to 28 mph without fatal injuries to either the subjects or fetuses (Van Kirk and King, 1969). Another study compared effectiveness of present lap belt and combination lap-shoulder belt systems on pregnant baboons (Crosby et al, 1970). These researchers found that in simulated 26 mph frontal barrier crashes, 50% of the lap-belted mothers lost their fetuses, compared with 8% fetal mortality when the mother wore both lap belt and shoulder harness. At this level none of the "mothers" sustained any significant injuries. An American Medical Association committee in 1967, and again in 1972, strongly recommended that pregnant women wear seat belts, but noted that only limited work (noted above) on restraint systems designed specifically to protect pregnant mothers had been conducted (JAMA, 1972).

One aspect of the biomechanics of impact protection for pregnant females, as well as other occupational requirements, relates to the degree of increased body girth. It is not uncommon for protective restraint belts to be too short to go around the pregnant woman, particularly when she is also wearing a heavy coat.

In addition to the biomechanical aspects, a wide range of human factors problems remain to be resolved. A recent labor dispute between air carrier flight attendants and the air lines revolved about working conditions and the occupational capabilities of a pregnant stewardess to carry on her work. At present a study of teenage pregnant women in underway at the University of Texas at Austin; however, no results are yet available (personal communication, 1977).

Other problems are encountered by the pregnant woman in such otherwise normal occupational activities such as driving a car, sitting at a desk, or working at a bench. The range of girth dimensions, any changes in body C.G., or effects upon range of motion apparently have not been studied and published. Armstrong (1977) recently addressed physical work of the pregnant woman. No anthropometry of the pregnant female has been published to date. In 1977 equipment was designed for a preliminary anthropometric study at HSRI in conjunction with the School of Medicine of the University of Michigan; however, this was not initiated due to lack of funding.

3. Elderly Males

While a fairly large literature exists relative to male anthropometry, most has been conducted on military populations which may not be representative of the general national population. Military populations by definition consist of young, physically fit individuals, highly selected. Since minimum retirement age is reached between 38 and 48 years, few older individuals are found in such surveys. As previously noted, the most recent U.S. civilian anthropometric study is the Public Health Examination Survey of 1959-1962 of the U.S. population of 18-15 years ago. In this survey 265 males from age 65 to 74 and 72 males from age 75-79 were included for a limited number of measurements.

Some male anthropometric studies have been conducted on individuals engaged in specific occupations. An example is the 23 dimensions taken on 2,993 law enforcement officers (Martin et al, 1976). However, the mean age for this group of males was 30.7 years, with 99th percentile in age 59.6 years.

The most recent study which included elderly males (to 74 years) was conducted utilizing 100 civilian males and females structured to statistically represent the U.S. population as noted previously. Measurements were taken on head and neck anthropometry, sagittal plane range of motion of the head and neck, determination of the response of head and neck muscles to low levels of acceleration, as well as measurement of voluntary isometric strength of neck flexor and extensor muscles (Snyder et al., 1975;1978 in preparation).

4. The Obese

It is significant to note that the Department of Commerce standards issued by the National Bureau of Standards (1971) show 16% (or over 17 million) of the U.S. women as being outside the sizing system for clothing. No study of anthropometry of the obese segment of the population *per se* has been found in the literature.

The author has taken limited measures on one male subject who was participating in an obesity weight reduction program conducted by the University of Michigan Medical School. This subject had reduced from 750 lbs to 504 lbs at the time of measurement, and had an 84 inch waist. One reason why a study has not been previously done is that standard anthropometry is not very practical on such individuals due to the inability to locate skeletal landmarks. This individual had worked as a professional driver, and as a teamster was unable to pursue his occupation due to his obesity. It is believed that there are many such individuals in the general population. However, to the author's knowledge the special problems of this segment of the population relative to work environments has not been studied.

Yet clues are known. The effect of obesity upon range of motion, for example, may be significant. Variations exceeding 10° in a given movement are common findings between fat and thin groups of both males and females (Sinelnikoff and Grigorowitsch, 1931).

V. FUTURE RESEARCH REQUIREMENTS AND PRIORITIES

Based upon the findings summarized in the preceding conclusions, it is recommended that research attention be given to the following general areas. In most cases no published data have been found or that which is available is either not directly applicable or is of extremely limited value.

- Study of female human factors and biomechanics requirements for various occupational environments.
- A comprehensive study of female strength capabilities, including seated forces applied to pedal and standing push forces.
- Anthropometry studies which can provide comprehensive measurement data relative to the elderly of both sexes, the pregnant female, the obese, and the physically disabled populations.
- Study of the requirements of the left-handed with respect to human factors design, biomechanics, and strength abilities.
- Information on work environment requirements for the pregnant female relative to human factors, range-of-motion, strength lifting capabilities, and biomechanics factors influencing performance and health.
- Study of the disabled, and particularly paraplegics and amputees, to obtain more comprehensive data on strength, human factors workspace design requirements, range-of-motion, and biomechanics capabilities.

Since some 52% of the population is represented by the female, priority should be given to this major proportion of the population grossly under-represented in previous research studies, with secondary emphasis upon the disabled, the elderly, left-handed, and the pregnant female.

APPENDIX

A. ANTHROPOMETRY

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