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A NEW METHOD FOR ASSESSING FATNESS FROM AN ANTHROPOMETRIC STUDY ON 8799 BRITISH ADULTS

A THESIS SUBMITTED TO THE UNIVERSITY OF GLASGOW

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BY

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CONTENTS

CHAPTER 2

METHODS

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SUMMARY

The aim of this study was to develop a method for measuring an individual's fat content, which was both simple and inexpensive and could therefore be used by relatively inexperienced researchers in large scale field studies.

At present the most popular field methods for assessing 'overweight' are weight for height tables based on Insurance Company data, and weight-height indices. The methods chapter points out the major limitations of these methods and describes how they cannot differentiate between weight due to bone, muscle, water or fat.

Another popular field method is to measure skinfolds at a few predefined sites and convert these to a fat content using regression equations. Although this method allows 'fatness' as opposed to 'overweight' to be assessed in the individual, it has the disadvantage that the observer requires some training, which is not always feasible, and carefully calibrated skinfold calipers are essential. It is for these reasons that a new field method, requiring minimal training and equipment was sought.

This study was carried out on a group of 6,495 males and 2,304 females aged 16-64y, selected, as described in Chapter 2, from both the British Armed Forces and the civilian population. The measurements taken from each individual were height, weight, 4 circumferences, 4 boney diameters and 4 skinfolds. Using the equations of Durnin and Womersley (1974) and Siri (1956) the skinfolds were converted into a value for percent body fat, and fat free mass (FFM) was calculated by subtracting fat mass from body weight.

The height and weight results were compared with the results of the Office of Population Censuses and Surveys (OPCS), 1981, UK survey. Since the OPCS survey was believed to be representative of the UK population, the comparison allowed an assessment of possible sampling errors.

Variations in anthropometric results related to geographical origins and social class (SC) were also examined, within Chapter 3, together with age related changes.

Within the Forces, civilians and OPCS samples respectively, mean height had

values of 175.9cm, 175.6cm and 173.8cm. Within the female samples, these 3 values were 163.6cm, 162.4cm and 160.7cm. The differences between the 3 populations were due mainly to the facts that the Forces selection procedure includes a minimum height cutpoint for many occupations and that the civilian selection was not very random. When predicting percent fat or FFM however, these differences appeared to be relatively unimportant.

Although height appeared to vary little with age, it did vary in relation to geographical region. In general, the northern regions had slightly smaller means for most of the anthropometric measurements, when compared to the southern regions. In addition, there was a slight tendency fof height to decrease with SC.

Mean weight increased with age from 65.5kg in the Forces male 16y olds to 80.0kg in the 50-56y olds. The Forces and civilian females kept their weight around 61 and 57kg respectively, between 17 and 29y, after which it rose steadily. Most of these weight increases were due to increases in fat content, since between the 16-17y and over 50y olds, mean percent fat rose from 13.4% to 27.2% and from 28% to 35.7% in the Forces males and females respectively.

FFM also varied slightly with age, especially in the male sample. In the male Forces it averaged 56.5kg, 61.8kg and 59.6kg in the 16y, 25-29y and 50-56y olds. The initial rise was mainly reflecting growth in the younger subjects. The subsequent changes are discussed in detail in Sections 3.2.10 and 3.2.11.

When matched for height and age the Forces males had FFM values on average 2.5kg larger than the civilians and this reflected a larger mean 'build'. This had to be taken into account in order to produce prediction equations applicable to both populations. There was little difference in fat content between the 2 groups.

The Forces females were of a similar 'build' to the civilians, but on average 1-2% of body weight fatter. This made no difference to the regression equations.

Section 3.4. describes the calculation of regression equations which predicted fat content and FFM. Although initially both FFM and percent fat were used as dependent variables, the prediction of FFM was the more accurate and therefore it was used in preferance.

The males were initally divided into height, weight then age groups but since the regressions predicting FFM in age groups were the most accurate, age was chosen as the final grouping variable in both sexes. The number of age groups depended on the similarities between different ages, and was calculated using a F-test.

Using the BMDP package of computer programmes, the variables height, weight, calf circumference and ulnar diameter were chosen from those measured as the 'best' to predict FFM in the male sample. In the females, the 'best' variables were height, weight and upperarm circumference. The regression equations are in Tables 90 and 91.

The final 7 male and 2 female age related regression equations were initially calculated from the Forces data, and cross validated on the civilian sample. The range of standard errors of the estimates (SE_E) in both samples was 1.54-2.39kg in the males and 1.44-1.80kg in the females. Approximately 95% of the prediction errors would lie within $\pm$ 2xSE_E.

Overall, FFM and hence percent fat could be predicted with greater accuracy using these regression equations than using weight-height indices or tables. The method is also simple enough to be used by untrained observers, in field studies.

CHAPTER 1

1.1. GENERAL

1.1.1. Historical Comment on the Measurement of Body Composition

Human body configuration has been a subject of interest for many centuries, and in different eras different aspects have received the focus of attention. The study of whole body composition by anthropologists is however a fairly recent development.

Originally, physical anthropologists tended to measure the skeleton only, because skeletal remains of varying ages and origins were fairly plentiful. The science was highly quantitative, and any qualitative descriptions such as skin or hair colour were carefully excluded. In addition, the influences of any variables other than skeletal, such as muscle or fat mass, were minimised and excluded from the measurements. Since the skeleton comprises only about 20% of the FFM (von Liebig, 1874; Forbes et al, 1956) then a vast area of anthropology was still to be explored.

Human body configuration however has been of interest to groups of individuals, other than physical anthropologists. Growth and the consequential bodily changes have been described as far back as the Greek philosophers who related it to a series of 7-year phases, or hebdomads. Anthropometry itself, i.e. the measurement of the body's dimensions, developed from the arts and the search for an 'ideal' God-like image. Since man was made in God's image, the dimensions and proportions of the 'ideal' man were considered close to God, and the artist attempted to express them by creating ideal, life-like and thus God-like images. A more detailed historical account is given by Tanner (1981).

1.1.2. Growth of Surveys

In a move away from these rather philosophical approaches to anthropometry, during the 19th century attention began to focus on public health, and surveys were established to examine its many aspects. Because of growing concern for child health, and working conditions, the first surveys were carried out mainly on factory children, partly in an attempt to relate stature with age and thus pinpoint stunting of growth possibly due to working conditions and undernutrition. Francis Galton, in the late 19th century, initiated an anthropometric survey in schools, in order to examine secular changes in height, differences due to environment and, later, hereditary factors. Similar studies were carried out at about the same time in Europe and America, by scientists such as Pagliani and Bowditch respectively, and the first skinfold measurements were taken over the biceps of children by the German, Kotelmann, at the turn of the century. (Tanner, 1981).

These mixed cross-sectional and longitudinal studies have been developed and continued into the 20th century, with much of the work still centering around children and adolescents. Many National surveys have been established, however, which record height, weight, and sometimes other measurements from a cross-section of all age groups, e.g. the Office of Population Censuses and Surveys (OPCS) in Britain, which records height and weight. More local, large-scale surveys have also been carried out, e.g. Montegriffo (1968) on London and overseas populations, and Kemsley (1950).

A major limitation of these studies is that they produced average values for height and weight from measurements obtained using inaccurate methods. Height, for example, in some of these studies was determined with the subject wearing shoes and in many cases weight was measured with him wearing indoor clothing. Because of this methodology, estimated corrections for shoes and clothing had to be made which can obviously lead to a certain degree of error.

Unlike many of the early 19th century anthropometric surveys, which were needed to pinpoint the relationship between undernutrition and poor environment, present-day surveys are more often required to pinpoint overnutrition and obesity. Obesity is becoming an ever increasing problem, particularly in developed nations such as Britain, and some of the reasons for wishing to assess it quantitatively and therefore treat it are explained in the following section.

1.2. REASONS FOR WISHING TO MEASURE FATNESS

1.2.1. Mortality and Obesity

Primarily due to the published work of the Actuarial Society of America in 1912, 1942, 1943, 1959 and 1960, there has long been an accepted association between 'overweight' and mortality. The American insurance companies at that time found that insured individuals at the top end of the distribution of weights for a given height and age showed a greater mortality risk. As has been pointed out previously by Keys (1980), these insured persons probably did not represent a random American sample, and the data collected from them was not totally accurate. Since only 2-3% of the sample, compared to 6-7% in the general population, reached the degree of 'overweight' necessary to pay an extra insurance premium, it is possible that many of the insured individuals did not admit to being overweight. Many of those who did admit to it possibly did not admit to other risk factors.

Several large-scale American studies, including the Minnesota and Framingham studies (Sorlie et al, 1980), together with various European studies (Rose et al, 1977; Carlson and Bottinger, 1972; Pyorala, 1978), now disagree with this simple association between increased relative weight and increased mortality risk. Instead, a picture is arising from many studies showing minimum mortality around average weight or weight index, and increased mortality for individuals both above and below this average (Dyer et al, 1975; Sorlie et al, 1980). These two studies, however, used different indicators of 'overweight'. Sorlie et al divided their subjects into 5 'build' categories, according to their weight for height, and they then related 'Build', i.e. weight, to mortality. Dyer et al, however, used the Quetelet Index, W/H^2, as an index of 'overweight' and related this to probability of death. When analysed in a linear manner, they found that the probability decreased as the index increased, a finding in direct opposition to the insurance phenomena. Noppa et al (1980) also found this negative correlation between death rate in women and overweight as assessed from the sum of the triceps and subscapular skinfolds. They also found a correlation between the Weight Index, (Weight (kg) x 100)/(Height (cm) - 100) and death from myocardial infarction. Rose et al, however, found no clear relationship between W/H^2 and mortality from coronary heart disease.

The results from these studies, and others, shows clearly that there is some confusion in our understanding of the relationship between mortality and 'overweight' or obesity.

1.2.2. Obesity and Disease

Current research and opinion on the association between obesity, 'overweight', and morbidity is not totally clear, but in general it appears that 'overweight' individuals are more prone to high blood pressure, high serum cholesterol levels, high levels of uric acid, high blood glucose and incidence of diabetes mellitus. They are also more at risk of developing osteoarthritis, gallbladder diseases, psychosocial disorders and, when undergoing surgery, are thought to be more prone to anaesthetic problems.

It is not the purpose of this report to review the literature on the ill effects of obesity, but interested readers could read the papers of Van Itallie (1979), Keys (1980), the Pooling Project Research Group (1978), Sorlie et al (1980), and Dyer et al (1975).

As an example of the confusion in determining the relationships and mechanisms involved between these diseases and obesity, the results of cardiovascular studies can be cited. Gordon and Kannel (1973), on examining data from the Framingham study, concluded that relative weight, i.e. (Actual Weight/'Ideal' Weight) x 100 was related to coronary heart disease (CHD), but not to myocardial infarction. 'Ideal' weight was taken from 'Height-Weight Tables'. Paul et al (1959), on the other hand, found no relationship between CHD and relative weight, but found an association when 'fatness' was assessed by 'skinfolds'. Noppa et al (1980) found a poor correlation between their Weight Index, as defined in the previous section, and myocardial infarction (MI) ($p = 0.12$), but no significant correlation between the sum of the triceps and subscapular skinfolds and MI ($p = 0.20$). Both indices, however, were significantly correlated to hypertension.

Overall, therefore, it appears that 'overweight' and probably 'adiposity' may be related to mortality and to diseases such as CHD and the others listed previously. In attempting to quantify the relationships and understand their mechanisms of action, one factor involved in the confusion is the lack of a simple, standardised field method for assessing 'fatness' as opposed to 'overweight' relative to some norm. Such a method could help to answer questions such as:

1. At what level of 'fatness' does the risk of mortality or morbidity increase?

2. In which diseases is obesity most important as a risk factor?

3. Would fat loss in an 'overfat' individual reduce the mortality/-morbidity risk?

4. Would fat gain in an 'underfat' individual reduce the mortality/-morbidity risk?

1.2.3. Other Factors

In addition to clarifying many results relating obesity to mortality or morbidity, there are many other areas in which some simple field measure of 'fatness' is required. Examples include nutritional or physiological surveys on populations, where it is often vital to differentiate between fat and fat-free mass. This is particularly important in developing countries, where nutritional aid schemes generally require this background information. In developed societies like our own where there is a lot of emphasis put upon physical appearance, there are many psychosocial reasons for wishing to measure fatness and recommend some 'desirable' weight. Wells et al (1962) described personality disorders in children, which were associated with obesity and were greatly improved once the children lost much of their excess weight.

The Armed Forces have their own specific reasons for wishing to assess 'fatness' and thereafter ensure that their members do not become fat to any limiting extent. Since Army policy states that its male members must all be trained infanteers no matter to which Corps or Regiment they belong, then they must also be fit in order to carry out this job. While fatness and fitness are not directly related, there are indirect asociations and a 'fat' individual would generally be fitter if he lost the excess fat. An 'overfat' individual instructed to lose weight would probably both reduce his energy intake and increase his energy expenditure by way of exercise, thereby indirectly becoming fitter. The 'overfat' person could also have mechanical difficulties in carrying out exercise, i.e. the extra energy required to carry the excess fat around or the extra weight and strain on limb joints.

1.3. MEASURING BODY FAT

Leading from the previous section where it was concluded that obesity is generally undesirable, this section discusses the choice of techniques available for measuring 'fatness'. This choice includes cadaver analyses, techniques which can only be used in a laboratory situation and finally techniques which can be used outside a laboratory, in field situations.

Because this study was based outside the laboratory and the final results are to be practicable without the use of laboratory equipment, the field techniques are described in most detail. The limitations of the simple 'height-weight' indices and tables are pointed out briefly in this chapter, and by utilising results from this study, they are described in more detail in the Methods chapter. The science of anthroposcopy is described, as is the more exact science of anthropometry, used throughout this study.

1.3.1. Dissection and Chemical Analysis

The only way to determine accurately an individual's fat content, is to carry out cadaver analysis, either chemical or anatomical.

These studies were first instigated by anthropologists in the 19th century. (Bischoff, 1863; Volkmann, 1874) but the number of cadavers analysed has been limited although at least 8 have been accurately analysed chemically and 22 anatomically. Although this method is obviously not suitable for most studies, it has been used to help standardise other methods, since it provides fairly accurate estimates of whole body composition. Some of these estimates are summarised in Tables 1(a) and (b) (Mitchell er al, 1945; Forbes et al, 1953; Widdowson et al, 1951; Womersley, 1974).

Table 1(a)

Body Composition Results from Chemical Analysis

Age (y)	42	35	25	46
Sex	F	M	M	M
Weight (kg)	45.1	70.6	71.8	55.7
Weight of Components expressed as % of Total Body Weight				
Fat	23.6	12.5	14.9	19.7
Protein	14.4	14.4	16.6	18.8
Water	56.0	67.9	61.8	55.7
Ash	5.8	4.8	6.4	5.5
Remainder	6.2	0.4	0.3	0.3
Weight of Components expressed as a % of Fat Free Body Weight				
Protein	18.8	16.5	19.5	23.4
Water	73.3	77.6	72.6	69.3
Ash	7.6	5.5	7.5	6.8
Remainder	0.3	0.4	0.4	0.5

Table 1(b)

Body Composition Results from Anatomical Analysis

% Composition of the 'Lean Tissue' (Total Body Weight - Adipose Tissue Weight)

Author	Sex	Age	Wt (kg)	Skeletal Muscle	Skeleton & Ligaments	Skin	Lungs	Liver	Nerve Tissue	Blood	GIT
von Liebig	M	30	55.7	46.5	23.1	7.1	-	3.5	3.5	0.9	17.4
Forbes et al	M	60	73.5	51.4	19.1	8.5	2.8	3.1	2.6	-	2.8
Bischoff	F	22	55.4	50.0	21.1	8.0	-	2.1	4.1	-	17.0
Briiel	F	55	46.0	41.2	23.0	7.4	2.3	3.8	3.6	6.6	7.9

GIT = Gastrointestinal tract plus associated glands

Tables copied from Womersley (1974)

1.3.2. Indirect Methods

In order to study living individuals, indirect methods for measuring body composition and fat content have been developed, and validated where possible against the cadaver analyses. The most common of these methods are described briefly below, but a more detailed description is given by Womersley (1974).

(a) Total Body Water

The measurement of Total Body Water (TBW) is based on the dilution principle i.e. a known amount of tracer is entered into an unknown volume and mixed thoroughly. The final tracer concentration is measured and is proportional to the unknown volume. Possible tracers include tritium, deuterium, antipyrene and urea.

Within the human body this situation is unfortunately complicated, since no tracer mixes quickly and evenly throughout the complete fluid volume, and they are each metabolised by the body at different rates. In addition, tritium is radio-active with a long half-life (Pace et al, 1947), Deuterium is expensive (Moore et al, 1963) and difficult to assay and antipyrene tends to dissolve in fat and bind to protein. Urea appears to be the best of these 4 traces, (McCance and Widdowson, 1951). No matter which tracer is used however, bulky analytical equipment and time are both essential for this technique.

(b) Extracellular Fluid Volume

Fat mass can be calculated from extracellular volume (ECV) using the equation of Grande, 1970.

Fat mass = Weight - (ECV + C + B) C = cell residue
B = bone mineral

The method is again based on the dilution principle, and has many of the same drawbacks as the estimation of TBW. Traces include thiosulphate, sucrose, manitol, inulin, Br^- and radioactive isotopes such as $S^{35}O_4$, but their different molecular sizes lead to them each measuring slightly different volumes. As a consequence, the measured volumes are often referred to by their tracers i.e. the 'thiosulphate space'.

(c) Total Body K^+

This method assumes that the fat-free component of the body has a K^+ content of approximately 68 mmol K^+/kg, while fat has a zero K^+ content. Since 0.00118% of this K^+ is naturally radioactive, emitting characteristic   - radiation (Miller and Remenchik, 1963), then if this is measured, the fat and fat free masses (FFM) can be calculated.

Although simple from the subject's point of view, this method requires expensive, bulky equipment.

(d) Densitometry

If an object consists of 2 components, M_1 and M_2 of known densities, D_1 and D_2, and if the object density, D_T is also known, then the relative proportions of M_1 and M_2 can be calculated using the formula:

$$m_1 = \frac{1}{D_T}\left(\frac{D_1 \times D_2}{D_2 - D_1}\right) - \frac{D_1}{(D_2 - 1)}$$

m_1 = M_1 expressed as a percent of total body weight. This rule still holds when the object is the human body and M_1 and M_2 are the fat and FFM components. Since density = Mass/volume, then the estimation of body volume will allow the calculation of body density. There are 4 standard methods for measuring body volume, and each is mentioned below, but Womersley (1974) goes into this method in particular in great detail.

<u>Underwater weighing</u>: this is the most commonly used method, mainly because it is the least complicated. The subject is totally submerged in a tank of water and the weight of water displaced, divided by the density of water, equals both the volume of water displaced and the subject's volume. Corrections for air in the lungs, atmospheric pressure and temperature are necessary.

<u>Air displacement</u>: this method has met with only limited success, and depends on the fixed relationship between pressure and volume in a sealed chamber. Corrections must be made however, for the heat and water vapour

generated by each subject.

Helium dilution: this method is again based on the fixed relationship between pressure and volume in a sealed chamber, but volume with the subject in the chamber is calculated using helium and the dilution principle.

Photogrammetry: Pierson, (1963) described this technique which involves taking photographs of the subject and drawing 'contour maps' in order to calculate volume. Recently, this technique has been developed more extensively, and appears to show promise in being able to accurately predict body density.

Once body volume and density have been calculated, the calculation of percent fat or FFM using the formula above depends on certain assumption about the constancy of their densities. These assumption are discussed in the methods section, and are acceptable in most instances.

(c) The Dilution Principle

Using the principle described in section (a), a tracer which is extremely soluble in fat only can be used to measure the body fat mass. Tracers used include nitrogen, cyclopropane and krypton and a major drawback is the long equilibration time required.

(f) Ultrasonography

This method, originally developed for cattle and swine, utilises the principle that when ultrasonic waves move from one tissue to another, some rebound, and the time taken for their return gives a measure of the tissue thickness. In humans however, this method is not well validated. (Booth et al, 1966).

(g) Electrical Conductivity

Booth et al (1966) described this fairly unpleasant technique, which involves inserting 2 wires into the subject and measuring changes in resistance which are caused by one wire moving from fat to muscle. The length of wire inserted into the subject when the change in resistance occurs, reflects the subcutaneous fat thickness.

(h) Electrically Induced Impedance

This method also depends on the difference in electrical conductivity between the different body tissues, and Harrison and van Itallie (1982) have suggested that as a lab method for use on infirm individuals in particular, it shows great promise.

The subject is placed within a solenoidal coil through which is passed an oscillating current. The resulting electrical field induces a current and thereby a measurable impedance in the subject, which is proportional to his lean fraction.

(i) X-radiography/Roentgenography

On a clear x-ray, fat, muscle and bone can be differentiated and their thickness measured (Tanner, 1965; Garn 1957) but careful standardisation of the methodology, and in particular the filming technique, is necessary.

In order for any indirect method to be of value in a study of human body composition, its results must be well validated against both human cadaver analysis and other well established indirect methods. If not, then it is really only of value for comparative studies. This has not been the case with the methods of ultrasonography, electrical conductivity or electrically induced impedance because they were developed mainly from and for animal studies. The technique of electrically induced impedence does however show promise in the human field once it has been further developed and standardised using human subjects. (Harrison and van Itallie, 1982). One method which can never be directly validated is the measurement of the ECV and therefore it could never be ideal for body composition studies, where fat content was being assessed.

The use of fat soluble tracers is not a popular technique in man, not because of the problem in validating results, but mainly because the tracers tend to be toxic i.e. cyclpropane, or radioactive i.e. krypton and even the shortest equilibration time, using krypton, is about 2 hours. The method also appears to underestimate fat content and the results tend not to be reproducible.

Although the technique of x-radiography can provide useful information on overall subcutaneous fat distribution as well as on bone and muscle mass, it is also not a popular method because of the complexity involved in fully standardising the filming technique. The angle at which an x-ray is taken obviously influences the recorded tissue thickness.

The 'best' practicable and subsequently the most popular laboratory techniques for measuring fat content are therefore based on the initial measurement of total body water, total body ^{+}K or body density. Each has its own drawbacks.

The water content of the fat free body for example is on average about 72% of body weight but it can range between about 66% and 79% (Grande, 1973). These 2 figures would result in fat contents of about 5% and 20% in a male of weight 65.4kg and a total body water of 40.8kg.

The potassium content of the fat free body is not constant at 68.1 mmol/kg but varies between individuals and in particular between the sexes. In males alone it can range between about 66.5 and 72.9 mmol/kg (Grande, 1973; Womersley et al, 1976)

The density of the fat free mass (FFM) is not constant at 1.1 g/ml, as assumed in most densitometric analyses, but varies depending on age, sex, degree of obesity and possibly other factors.

Once these limitations are realised and taken into account where applicable however, these three methods do provide fairly accurate estimates of body fat, and as a result can justifiably be used to validate other indirect methods such as the electrically induced impedence method and the skinfolds technique.

1.3.3. Population and Field Methods

The indirect methods for measuring obesity mentioned in Section 1.3.2. cannot be used outside the laboratory because they lack simplicity. Field methods, have therefore been developed, but in their simplicity some of them tend to lose a degree of accuracy which is often not easily quantified or taken into account. The most popular methods are described briefly below and in more detail in Chapter 2.

(a) Weight - Height Relationships

The relationship between height and weight is often taken as an indicator of obesity, or more exactly, of 'overweight', and examples are the 'Desirable Weight-for-Height' tables which have been produced from mortality data collected by American insurance companies. As a consequence of these tables, many studies use Relative weight i.e. (Actual Weight/ 'Desirable' Weight) x 100 as an obesity index. Other examples are the many Weight-Height indices which have developed i.e. the Quetelet Index (W/H^2), the Ponderal Index ($H/W^{1/3}$) or W/H.

The main problem with these Weight-Height relationships, indices and tables is that they cannot differentiate between weight due to muscle, bone or fat. An 'overweight' individual is often automatically assessed as 'overfat' as opposed to muscular or large boned. Despite this obvious limitation, the indices in particular are still often misused and therefore the data from this study is used in chapter 2 to describe in detail how small ranges in the Quetelet Index can represent large ranges in fat contents, and therefore their association is not very strong.

(b) Anthroposcopy

This is the science of visual observation and description of physical traits which are not easily quantified. It can be a highly subjective science, requiring careful training in order to standardise the results, and since it is no longer commonly used it is not discussed in detail in Chapter 2, but is instead described in a little more detail here.

Anthroposcopy is distinct from anthropometry, since the latter involves quantitative measurements while the former does not. The distinction should also be noted between somatotyping and somatometry, the former being a branch of anthroposcopy while the latter is a branch of anthropometry. Sheldon (1940) produced a scheme of 'body typing' or somatotyping which has been probably the most influential. He rated each individual on a scale from 1 to 7 in three components (a) endomorphy: soft-roundness, (b) mesomorphy: predominance of squareness and muscularity and (c) ectomorphy: predominance of linearity and fragility. Although Sheldon was attempting to assess each individual's permanent characteristics, his classifications and in particular the endomorphy ratings, are generally used to describe both permanent and changing factors.

Several workers have related Sheldon's somatotypes to more easily quantified variables such as x-radiographic measurements (Reynolds and Asakawa, 1950) or body specific gravity (Dupertius et al, 1951). Dupertius et al also produced a regression equation, based on 81 males, to predict specific gravity;

Specific gravity = 1.1094 - 0.0119 (endomorphy rating).

This equation was naturally very dependent on the standardisation of the rating. When Damon and Goldman (1964) cross-validated it on 13 young men, they found a mean difference between percent fat calculated from the equation and densitometry of 3.4% of body weight. In terms of accuracy it was only 7th out of 10 equations cross-validated.

Brozek (1955) also produced a prediction equation from somatotype ratings, but this time Damon and Goldman (1964) found the equation to be more accurate than many other equations based on anthropometric measurements i.e. Behnke et al (1959), Hunt (1958) and Chinn and Allen (1960).

In summary, anthroposcopy tends to involve subjective techniques which are difficult to standardise without introducing some physical measurements, for example, from photographs (Parnell, 1958). Since simple physical measurements can be taken easily in most studies, the more quantitative science of anthropometry is preferable.

(c) Anthropometry

The techniques of anthropometry allow a quantitative description of the body through physical measurement of its dimensions. If photographs are used the method is known as photogrametry.

In any anthropometric study there is an enormous choice of possible measurement sites, but it is important from both the practical and statistical points of view to keep the number to a minimum.

From the practical side, a large number of measurements requires a lot of time which may not be available in field work. From a statistical point of view, if a predictive, regression equation is produced from a large number of variables, then the equation becomes descriptive as opposed to predictive.

The actual choice of sites has varied between studies. Initially there was little standardisation of either sites or methodology, but in 1969, the International Biological Program produced a handbook called 'Human Biology: a Guide to Field Methods' edited by Weiner and Lourie and updated in 1981 as 'Practical Human Biology'. This book presented both a set of anthropometric techniques which had been agreed by authorities in the field, and a recommended set of 21 basic sites plus 17 additional, optional sites. This recommended list included specific skeletal measurements, circumferences and also skinfold measurements.

The method of measuring skinfolds was first introduced by a German, Kotelmann, around the turn of the century (quoted by Tanner, 1981). It has an advantage over simply measuring height, weight, circumferences and diameters, because it allows the assessment of 'fatness' in the individual as opposed to just 'overweight'. For this reason, it was used within this study as the basic method for measuring each subject's fat content. Both the principles supporting it and the methodolgy are described in detail in the Methods chapter.

1.4. REGRESSION EQUATIONS WHICH ASSESS FAT CONTENT

Since at least 1912, researchers have taken simple anthropometric variables and used them to produce regression equations predicting fat content or a related, dependent variable such as body density. The predictor or independent variables have generally been either skinfolds alone or a combination including skinfolds, circumferences and diameters. The following section is a review of many of these equations, and supports the choice of the equations of Durnin and Womersley (1974), which predict body density from 4 skinfolds, to assess 'fatness' within this study. The measurement of skinfolds does however have an obvious drawback. It requires carefully calibrated skinfold calipers and the observer must be trained in order to take the measurements accurately. This study was instigated to establish another method for accurately measuring an individual's fat content, which does not require that the observer be trained or possess specialised equipment.

The 2nd part of the review therefore describes some equations which support the feasibility of this idea by predicting 'fatness' using circumferences and diameters, but not skinfolds.

Throughout the review, the results of cross-validation studies on the prediction equations are included, because the test of a good equation is its accuracy on a group of subjects other than the one from which it was calculated.

1.4.1. Equations which Include Skinfold Measurements

As early as 1921, Matieka had produced a formula to predict percent fat:

% fat = 0.13 x Surface Area x ½ (average skinfold thickness at 6 sites)

(Surface area was estimated from the nomogram of Sendroy and Cecchini, 1954).

Damon and Goldman (1964) cross-validated this equation on a group of 13 athletic young men aged between 18 and 29y and concluded that it overestimated body fat by on average 4.1% fat in his sample and was therefore unsatisfactory. Matiegka did not however fully describe his subjects and since it has been shown in this study that different age groups require different equations, if his experimental group were not within the same age range as Damon and Goldman's then it is not surprising that the cross-validation was poor. In addition, Damon and Goldman (1964) only measured two of Matiegka's six skinfold sites and therefore the comparison of results was not totally valid.

Brozek and Keys (1951) although not the first to measure body density in man in order to assess fat content, were the first group to relate density to skinfold thickness in order to calculate fat content. Behnke, Feen and Welham (1942) had in fact originated the idea of dividing the body into a Lean Body Mass (LBM) and fat component, each with relatively constant density and of using this to assess body fat content from measured total body density.

Brozek and Keys (1951) produced two equations, predicting specific gravity, one using the triceps skinfold and the other the subscapular skinfold. Both were based on college men of average age 20y. Pascale et al (1956) produced two equations using the same skinfolds, but predicting density and based on 88 American soldiers aged between 17 and 25y. Damon and Goldman (1964) cross-validated the equations from both studies against densitometric results from their 13 young males and concluded that the difference between predicted and densitometric fat percentage averaged $\pm$ 2.3% and $\pm$ 2% for the 2 studies repectively. Haisman (1970) also cross-validated Brozek's equations against 55 healthy British soldiers of mean age 22.6 $\pm$ 2.2y but he found a correlation of only approximately 0.69 between fat content estimated by the 2 equations and densitometry. The Standard Error (SE_E) were not however quoted.

Although the subjects in these 4 studies were similar, excepting that Damon and Goldman's young men included 1 Japanese and 1 negroid male and the 13 may have been more athletic than the other subjects, and although the methodology was similar, there was an important difference. The calipers used by Brozek and Keys (1951) had an opening tension of 35.4gm/mm^2 and a jaw surface area of 3mm^2, while for Pascale et al (1961) these figures were 10gm/mm^2 and 25mm^2 respectively. Damon and Goldman however used Lange calipers (Lange and Brozek, 1961) which exert a pressure of 10gm/mm^2 with a SA of 30mm^2, and Haisman (1970) used Harpenden calipers which exert the same pressure and have a SA of about 66mm^2.

While the Lange and Harpenden calipers produce similar results (Sloan and Shapiro, 1972) and are not very different from the calipers used by Pascale et al (1961) since they all exerted a fairly constant pressure of 10gm/mm^2 at all opening distances, they were very different from the calipers of Brozek and Keys (1951) which exerted a higher opening pressure and did not claim to exert a constant pressure at all opening distances.

Brozek and Keys (1951) also produced a prediction equation which included the triceps and 2 abdominal skinfolds, and Pascale et al (1956) an equation including the triceps and 2 chest skinfolds. On cross-validating these, Haisman found correlations of only 0.75 and 0.76 for the 2 studies repectively, when relating estimated fat to fat calculated from densitometry.

Although the SE_E's were not quoted by Haisman, the general comment from these cross-validation studies appears to be, that the relationship between the predicted value and the actual estimate of an independent variable will fall in a cross-validation group when compared to the original group, unless the groups and the methodology are well matched. These equations therefore tend to be specific to the original study group, and the various factors which must be taken into account to overcome this problem, become evident throughout this review.

Chinn and Allen (1960) predicted fat from anthropometric measurements in a broad cross-section of young European and Asiatic men, but Damon and Goldman found their cross-validation to be poor. This was at least partly due to the cross-section of ethnic groups within the original sample.

Adams et al (1962) and Edwards and White (1962) produced equations calculated from groups of hospital patients. When Haisman (1974) cross-validated them however, they both overestimated percent fat, as estimated from densitometry, by on average 4.8% and 4.9% respectively. Fletcher (1962) also studied male and female hospital patients aged between 15-72y and predicted body fat, as calculated using the TBW technique. This study was not cross-validated, but Fletcher, himself, stated that its accuracy was usually less than 10%.

An examination of Fletcher's subjects however showed them to include patients suffering from anorexia nervosa, obesity and chronic renal diseases. Although Fletcher stated that these illnesses did not appear to affect the skinfold measurements, it seem unlikely that the results from any study based on hospitalised patients, could be applied with accuracy to the average, healthy individual.

Durnin and Rahaman (1967) predicted body density from the sum of 4 skinfolds, and produced 4 equations of the form:

Density = 1.1610 - 0.0632 log (biceps + triceps + supra-iliac + subscapular skinfolds)

This study was based on measurements taken from 105 young men and women and 86 adolescent boys and girls, described as being 'of varying body builds - thin, intermediate, plump but very few were obese'. There was 1 equation for each sex and age group and the one quoted above was for young men. Log transformations were used because skinfolds and density are related in a curvilinear as opposed to rectilinear fashion, and the skinfold distributions themselves tend to be skewed.

This group demonstrated SE_Es of between ± 3-3.5% of body weight using their equations and the equation of Siri (1956) to predict percent fat and when Haisman (1970) cross-validated the equation quoted above on his sample of young men, he found a correlation of R = 0.76 between percent fat calculated from densitometry and this equation, and a mean difference of only 0.82 ± 2.9% fat. Of the 8 prediction equations he cross-validated, all of which were suitable for young men, he found this to be the most accurate. Katch and Michael (1969) on the other hand cross-validated Durnin and Rahaman's equation formulated from boys, aged approximately 13-16y, on a group of 40 16-18y olds and found a high mean error of 12.2% fat and a SE_E of 3.7% of body weight. The probable reason for this very poor validation was that Katch and Michael (1969) used Lange calipers with a jaw tension of 12g/mm^2 as opposed to the Harpenden calipers used by Durnin and Rahaman which exert a constant pressure of 10g/mm^2. In addition the sites of measurement may have been differed slightly. Durnin and Rahaman (1967) for instance, defined the supra-iliac site as just above the iliac crest on the mid-axillary line, while Katch and Michael took it, again on the mid-axillary line, but between the lower rib and the iliac crest. The age difference between the 2 groups of boys studied probably also decreased the validity of the cross-validation.

Katch and Michael (1969) again did not take into account age differences when cross-validating the equations of Sloan (1967) based on male 18-26y olds, and 4 other regression equations. These differences were likely to at least partly account for the relatively large prediction errors in the cross-validations.

The review has so far shown that when calculating prediction equations for use on individuals other than those within the original population, factors which must be taken into account include age, sex and the methodology used in taking the measurements. There are however other, more minor factors involved, such as fitness, ethnic group and fat free mass composition.

Flint et al (1977) set out to test the validity of some prediction equations on a group of 60 females aged between 12 and 78y of varying levels of fitness. Again, the equations were validated against densitometry. They verified the importance of most of the factors mentioned, but this group and Wilmore et al (1970) both found a change in the accuracy of predictions when used on groups of fit and unfit subjects. This could have been due to variations in FFM density between the groups, which would have altered the accuracy of estimating fat or FFM by densitometry.

Other studies have also been carried out which have examined the specificity of regression equations to ethnic groups. Steinkamp et al (1965) used simple anthropometric measurements, including skinfolds, to predict body fat in white and negro populations. After validating them against both densitometric and total body water techniques they found that the 2 ethnic groups required different equations to produce the best predictive accuracy.

Satwanti et al (1977) measured body density by underwater weighing together with 16 other anthropometric measurements in a group of 65 Punjabi women aged 18-30y. Fat content was calculated using the equation of Siri (1956). They then cross-validated 12 published, European, regression equations using this data, and 'revised' them in order to increase their accuracy in this Indian group.

A surprising fact about the data published by this group was that the average fat content of the women, as calculated by densitometry, was only 15% $\pm$ 7.95%, which is very low compared to the European average of about 25% described in Section 3.3. Since they claimed to use standard methodology the reason for this difference is obscure. The European equations predicted fat contents around 20-25% of body weight and it was this difference between measured and predicted fat content which necessitated Satwanti et al modifying the regression equations to suit their sample. Whether or not there is a difference in either FFM composition or in the relative distribution of internal and subcutaneous fat between the 2 ethnic groups is not at all clear from this data.

Jones et al (1977) measured skinfolds and body density in a group of 120 Indian males of average age 26y. On relating the skinfolds to body density and comparing this relationship with results from European subjects, they found that for any measured body density the Indians tended to have a larger skinfold measurement. This was most obvious in a group of Gurka subjects. In order to explain these differences Jones et al suggested that the Indians had a higher percent of subcutaneous fat, that their skin thickness appeared to be very slightly thicker and that skinfold compressibility may vary between races. In addition, they found from radiographic measurements of the femur that the Gurkas had signficantly thicker bone cortices than the other Indian groups. If this could be related to bone density then this group had a higher FFM density than the value of 1.1 kgm^{-3} assumed normally and therefore the equation of Siri (1965) was not necessarily applicable.

Katch et al (1979) tried to produce a less population specific method for estimating both fat and FFM. They returned to Matiegka's plausible idea of 1912 which proposed that body fat could be estimated from the product of surface area (SA), skinfolds and a constant. SA however was calculated using only the variables height and weight and on considering the variations in 'build' and body composition which have been demonstrated in this study within individuals of similar heights and weights, the accuracy of this formula becomes questionable: SA cm^2 = 3F x H x 176.2 (Dubois, 1936). The theoretical prediction equation produced by Katch et al (1979) was:

$$\% \text{ Fat} = \frac{\text{Skinfolds}}{3F} \times k\ (SF)$$

k (SF) = skinfold constant dependent on no. of skinfolds

$$F = (W/H)^{1/2}$$

This equation was then validated against percent fat calculated by densitometry and bone diameters, but although average differences were quoted, standard errors were not. When validated against densitometry the maximum differences averaged 3.9 $\pm$ 2.3% body fat. These measurements were

were however taken on professional American footballers who are generally unusually 'well built' and the assumptions on the constancy of the density of FFM are unlikely to have been valid. One footballer had his fat content calculated as 0.2% fat by densitometry. Since this is an important assumption in the calculation of body fat from densitometry then the method and therefore the cross-validation were not valid. It appears to be unlikely overall, that one prediction equation could be applied across all population subgroups.

Several groups have looked at the question of whether including girths and bone diameters with skinfold measurements, in regression equations, increases their predictive accuracy. Michael and Katch (1968) measured both skinfolds and girths, but not bone diameters, on 48 17y old boys, whose body densities had been calculated by densitometry. This group concluded, in agreement with Durnin and Rahaman (1967), that the inclusion of girths did not substantially improve the predictive accuracy. They also suggest that some standardisation of the skinfold sites included in regression equations would be useful, because different research groups tended to select different sites, and there was no general set of variables which could be used for several different populations. Michael and Katch (1968) in fact suggested that percent fat should be estimated from the most commonly used skinfold sites i.e. triceps, scapula and iliac. A natural extension of this idea would be for 1 research group to use a standard set of skinfold sites and produce predictive regression equations for the complete male and female age range. This did not happen until the work of Durnin and Womersley (1974).

Again looking at the accuracy of using skinfolds alone, circumferences and diameters alone, or a combination of both types of anthropometric measurement, Katch and McArdle (1973), measured 5 skinfolds, 13 circumferences and 8 bone diameters on 53 college aged men and 69 college aged women. They then chose independent variables to predict body density, as determined by densitometry. In males, they found the 4 'best' to be the triceps and subscapular skinfolds plus the abdomen and forearm circumferences, producing an R value of 0.89 and SE_E of 0.0066g/ml. In the female group, the 'best' 4 sites were the iliac and scapula skinfolds, elbow and thigh circumferences, and this time $R = 0.84$ and $SE_E = 0.0086$g/ml. As will be discussed in the next section however, this group also found that circumferences above could be used to predict density just as accurately as skinfolds alone.

Womersley and Durnin (1973) described how in a group of males and females aged 16-72y, the inclusion of variables other than 4 skinfolds in equations predicting body density brought little improvement to their accuracy except in the young male and older female groups. This result was in general agreement with Michael and Katch (1968) and Durnin and Rahaman (1967), but Womersley and Durnin did not look at the possible accuracy of using circumferences and diameters instead of skinfolds, in their equations.

Pollock et al (1975) did not agree with one of the Durnin and Womersley (1973) conclusions. In their study of young and middle aged women they found that the best prediction of body density was found with a mixture of skinfolds, girths, circumferences and in older women, bra cup size. Going from skinfolds alone to a combination of measurements improved the SE_E of prediction in young women (mean age = 44y), from 0.0091 g/ml to 0.0079 g/ml and in middle aged women (mean age = 44y) from 0.0076 g/ml to 0.0065 g/ml. Womersley and Durnin (1973) had found this improvement in their older group also, but not in their younger group. The best independent variables in Pollock et al's young group were the supra-iliac and thigh skinfolds, chest-low girth, waist girth and chest and knee diameters. In their older group they were the axilla, supra-iliac and thigh skinfolds waist and chest-mid girths, chest diameter and cup size. This group also believed that each age group should have its own set of predictive equations, but they did not take up the suggestion of Michael and Katch (1968) and test the accuracy of using one standard set of independent variables in each age group.

Pollock et al (1976) carried out a similar study on young and middle aged men. They again found that the inclusion of extra variables together with skinfolds when predicting body density, improved the accuracy, and in agreement with Womersley and Durnin (1973) this was more the case with the young men (mean age 20y) than the older men (mean age 44y). The inclusion of extra variables reduced the SE_E in young men from 0.0082 to 0.0069 g/ml and in older men from 0.0082 to 0.0074 g/ml. They again concluded that each age group should have its own regression equation but still did not state whether these equations could or could not use the same independent variables.

These studies therefore provide inconclusive results, as some groups found that skinfolds alone provided the most accurate estimation of body density or fat content, while others found that circumferences or diameters should be included. On considering all the results however, it would appear that the inclusion of circumferences or diameters with skinfolds is of relatively minor importance as long as a prediction equation takes into account the more important factors of age, sex, methodology, ethnic origins and possibly even activity.

It can also be concluded that although these equations do tend to be population specific, if these factors are taken into account their predictive accuracy will still be high.

In an extension of their work in 1967, Durnin and Womersley (1974) published 5 age related regression equations for each sex, predicting body density from the sum of the biceps, triceps, subscapular and supra-iliac skinfolds. Between the ages of 17-68y approximately, the mean SE_Es were 0.0084 g/ml in the males and 0.0102 g/ml in the females.

This was the first time that one group had produced a set of age specific predictive equations which spanned almost the complete adult male and female age range as opposed to only population subgroups. It was also an innovative and welcome move to use a standard set of independent variables in each equation. These equations are described in more detail in the Methods section and small cross-validation studies by other groups have supported their accuracy (personal communications to J V G A Durnin).

Because of this accuracy and versatility, these equations were used throughout this survey to predict each individual's fat content.

1.4.2. Equations not Including Skinfold Measurements

All the equations in Section 1.4.1. involved the measurement of skinfolds, but this section reviews some equations which predict fat content, or some related variable, but which do not include skinfold measurements.

In 1959, von Dobeln and Hechter both produced equations predicting fat free

weight (FFW) and LBW respectively. Von Dobeln's subjects were 16 male and 16 female physical education students aged 19-33y while Hechter's were 31 Naval male personnel, aged 20-52y.
The equations were:

von Dobeln: FFW = 15.1 (Ht (m)^2 x femural condular breadth (dm) x
(1959) bistyloid radioulnar breadth (dm))$^{0.72}$

Hechter: LBW = 519 x 10^{-5} (chest diam (cm)$^{.75}$ x wrist diam (cm)$^{.43}$
(1959) x ht (cm)$^{1.18}$)

Neither equation includes skinfold measurements. When cross-validated by Wilmore and Behnke (1969) on a group of 133 young males it was found that both methods underestimated FFW as calculated from densitometry. These poor cross-validations were at least partly due to the fact that the studies were in fact not truely comparable. Von Dobeln's results are of little use generally, because he grouped both sexes together i.e. males with fat contents on average around 10% of body weight, and females with averages around 20%. Wilmore and Behnke on the other hand only examined a group of males, with an average fat content of 14.5%. The difference in the male fat content between the 2 studies, also suggests either an error in methodology, or that von Dobeln's subjects were very lean, as may be expected of PE students.

Another factor leading to this underestimation of LBM was that Wilmore and Behnke (1969) did not appear to take into account the fact that FFW does not equal LBW, since the former does not include any essential lipid component while the latter does.

Hechter's study, was more similar to the cross-validation study with the exception that it encompassed an older age range.

These poor cross-validations however, do not detract from the fact that the prediction equations did appear to be accurate when applied to the original study groups.

Behnke et al (1959) developed a slightly different method for predicting both total body weight and body fat. Although the prediction of weight has little value in itself since it is easily measured, this group was trying to establish the idea that constants or equations calculated from one group, could be applied to other groups or individuals.

Behnke et al (1959) viewed the body as an approximate cylinder with radius R, and applied standard, geometrical formulae as shown:

$W = R^2 h$ $\quad R = \frac{W}{h}$ $\quad$ W = weight

h = height

They also derived the equation, k = D/R where k was a constant required for each measurement site, D was the average measurement at that site, calculated from the 31 subjects and R was the average radius from the same subjects. They believed that in order to predict body weight only 2 anthropometric measurements were required and that these were the buttock circumference and height. To calculate this prediction in any individual, the constant, k, calculated from the original population was applied within the equation R = D/K to calculate R, which was in turn substituted within the equation $W = R^2 h$.

In order to predict fat content or the 'mass of excess fat', Behnke et al (1959) established a set of 4 standard trunk measurements (group A) and 7 standard measurements around the extremities (group B). They believed that group A provided an indication of the subcutaneous and internal fat while group B reflected mainly muscular development. It should be noted however that the group A and B variables were not totally fixed.

Within groups A and B the measurement were summed and divided by the relevant k values calculated from the Naval volunteers. This produced two R values. Values of the weights for segments A and B were then calculated from the original equation: $W = R^2 h$, and the two weights compared.

If the two weights were the same, then it was hypothesised that the subject had the same fat content as the original Naval men i.e. 19% fat, and that this was an 'acceptable' fat content. If the 'A' weight exceeded the 'B' weight then he was over 19% fat and vice versa. The actual extent over or underweight was proportional to the difference between the two weights.

The correlation between predicted and actual fat content was however never above 0.8 even in the original Naval subjects and therefore the method was most unlikely to be accurate in any other group. It is also not a simple procedure either mathematically or in anthropometric terms since it requires 11 measurements and 11 constants.

In 1953, Behnke had developed the idea of the Lean Body Mass (LBM) index, LBM/h (kg), which he believed allowed LBM comparisons to be made between individuals by smoothing our height differences. Although similar to the Quetelet index, W/H^2, this index differentiated between weight due to fat and the fat free mass.

In 1959 therefore, Behnke expanded his idea of an ideally cylindrical body, in order to predict LBM. He in fact predicted the skeletal mass and from this the LBM, on the assumption that the skeletal fraction is fairly constant. As is pointed out by Grande (1973) and Womersley (1974) this is a questionable assumption. Behnke validated his new prediction equations by measuring body density using the helium dilution technique and by measuring TBW using tritium and assuming the tritium space to occupy 72% of the FFM.

When Behnke himself compared his results using the 2 validation methods he found that TBW calculated using tritium was 76.5% of the FFM calculated by densitometry. There was a difference of on average 3.7kg in the FFM calculated by the two methods and in one individual it reached 15.3kg.

It appears therefore that the validity of Behnke's method was not accurately checked because of these basic inaccuracies. When cross-validated by Young and Blondin (1962) on a group of young women and by Damon and Goldman (1964) on young men, the equations were found to be inaccurate. Damon and Goldman found that the absolute mean difference between fat calculated from the equations and densitometry was 3.7% of body weight. When describing another group of 34 males, Behnke (1961,a) quoted fat contents calculated from the equations ranging from 2 to 31% of weight and this extremely low value of 2% again strongly suggests an error in the basic calculations.

Behnke (1961,a; 1961,b) attempted to study 'build' by 'fractionating' weight into 11 segments and Taylor and Behnke (1961) extended this idea by grouping the segments and comparing the group 'fraction weight'. As Taylor and Behnke pointed out themselves however, interindividual variation is too great for this method to be of any value.

Despite the general failure of this relatively complex scheme for assessing fat content, a group who did have success when predicting body density, initially calculated from underwater weighing, without using skinfolds, was the team of Katch and McArdle (1973). Their results, from 53 college aged men suggested that the 'best' combination of skinfolds or circumferences alone produced identically accurate predictions. 3 skinfolds or 3 circumferences gave SE_Es of 0.0072 g/ml. In their group of 69 females, the best combination of circumferences gave an SE_E of 0.0094 g/ml while the 'best' skinfolds alone showed a SE_E of 0.0100 g/ml, and therefore the equation using circumferences was the better.

In 1978, Weltman and Katch attempted to produce a non-population specific method for predicting body volume and thus body fat, without including skinfold measurements. Their 'best' equation, using thigh, girth and weight as independent variables, demonstrated a SE_E of 0.651L, equivalent to about 0.012 g/ml or 5% fat at a weight of 58kg and fat content of 26%, the average weight and fat content in the female study group.

This equation, originally calculated from a group of 24 college aged women, was then cross-validated on childen, college aged men and women and middle-aged men and women in order to assess its population specificity. The resulting SEs were 0.72L in the children, 0.69L and 0.86L in the young and old men, and 0.63L and 0.78L in the young and older women respectively. In terms of percent body fat, 0.72L was equivalent to about 9% fat in the children, the large error being due to their low mean weight, and the male and female mean errors were 2.8-4.6% and 4.0-5.9% fat respectively. The equation was therefore not sufficiently accurate to apply to children or middle-aged adults because a mean SE_E of 9%, 4.6% or 5.9% fat represents a substantial error when it is remembered that 95% of the individual errors fall between $\pm$ 2 x SE_E. Because the cross-validation samples were very varied, the correlations between predicted and 'actual' volume were misleadingly high at 0.99.

Overall, it appears that these prediction equations of Weltman and Katch (1978) were not particularly accurate even in the original sample group, and could not be applied across all population groups.

It should be noted that again this study had been based on the idea of viewing the body as the sum of various geometric shapes and this method had also not worked for Behnke and his co-workers. There is still a requirement therefore, for a set of equations which can accurately predict fat content or a related variable across both the male and female adult age range.

1.4.3. Summary

Many investigators have developed regression equations which predict body density, specific gravity, FFM, LBM or fat content from anthropometric measurements. Where skinfolds have been included in the equations, the best set of equations encompassing the male and female adult age ranges are those of Durnin and Womersley (1974). These equations were therefore used throughout this study to predict each individual's fat content.

In field studies there are some disadvantages to measuring skinfolds and it would be advantageous in many instances to have a method which could still assess fat content accurately in the individual, but which required little more than circumferences and diameters to be measured. Several workers have studied this possibility and considered it feasible but none so far have produced an accurate set of prediction equations which can be used across the male and female adult age range.

The main purpose of this study was to produce such a set of equations.

CHAPTER 2

METHODS

2.1. GENERAL ROUTINE OF THE FIELD WORK

Every location visited, whether Service or civilian, varied slightly from the others and therefore there was no totally fixed routine to the field work. In general, however, the pattern was mostly the same and is described below.

In order to start work first thing on Monday morning, the field workers usually travelled to each location on the preceding Sunday. They were accommodated in the Officers' Mess at each Service establishment, and in local guest houses or hotels when visiting civilian companies. If the location was within about 50 miles of Glasgow, however, the team travelled back and forth each day.

A room with a table, a couple of chairs and if possible a changing area was requested before the team carried out each visit. The rooms provided ranged from a map room at the back of a squadron's hangar or the ladies' powder room in the basement of a bank, to entire wards in a medical centre and on one occasion a lecture theatre. On discovering that it was sports day at one RAF base, the team even carried out the measurements in a marquee on the edge of the football pitch. Where possible, changing rooms were provided, but generally this was either not possible or not practicable, and subjects had to undress either behind screens which were provided by the establishment, or in one corner of the room. Most subjects were very co-operative, and these inconveniences were regarded as amusing rather than annoying.

The number of individuals measured each day varied from about 30 to on occasions 100, but a comfortable number was around 60 or a rate of 10 - 12 per hour. The field workers normally worked totally independently, carrying out their own measurements and doing their own recording, and therefore two subjects could be measured simultaneously. This was found to be the quickest method. Limiting factors to the numbers of people seen in one day included:

1. A lack of space at some locations to have two subjects undressed and waiting to be measured while the measurements were carried out on two others.

2. A request from some subjects to be measured entirely on their own, which was always complied with.

3. A mixture of males and females arriving to be measured at the same time. The two sexes were always measured separately, and in arranging visits it was always requested that they come at different times of the day, although this was not always practicable.

4. The lack of a timetable for the attendance of subjects. While many establishments timetabled volunteers to attend, others found this impracticable, and instead the volunteers attended at their own convenience. This meant that the research team could spend long periods of time with no-one to measure, followed by exceedingly busy periods.

5. The size of the office/factory being visited. If the establishment consisted of small offices or units, then often only one or two people from each unit could be spared at a time to be measured. It was only when these people had returned to their work, that someone else would be free to attend, and therefore the attendance was not in a continuous flow.

At some locations, when attendance was low the research team went round the office or workshop publicising the project and persuading reluctant individuals to participate.

In general, it was thought that the initial response rate achieved at any establishment seemed to depend on the enthusiasm for the project held by the individual at that establishment who was publicising and organising the project. It was also often found that the response was proportionally higher at small establishments, where people tended to know each other, and once some had volunteered others often followed.

The reasons behind the survey were explained to all the subjects either individually or in groups.

The hours worked at each location were arranged to suit the volunteers, and tended to be 8.30 a.m. - 5.00 p.m. at Service establishments and 9.00 a.m. - 5.30 p.m. at civilian locations. These hours were not rigid, however, and at a few Service training bases the measurements were carried out at weekends and in the evenings, as these were the only times that the recruits or students were free.

The length of time spent at each location varied from one day to two weeks, and was dependent entirely on the number of volunteers. Since the research team knew these numbers approximately before each visit, they arranged their timetable so that several locations would be visited on any one field trip if it was appropriate. Field trips normally lasted 2-3 weeks, but near the end of the project this was often reduced to one week because consecutive weeks did not suit the companies involved. Appendix A, Tables 1-4, list the establishments visited and the numbers of people seen at each.

2.2. SUBJECT SELECTION FROM THE 3 ARMED FORCES

2.2.1. Introduction

The aim in the selection of subjects was to see a broad selection of about 5,000 males from the UK Regular Forces (a sample of approximately 1.6%) and as many females as possible. The final figures were 5,429 males and 1,123 females.

The subjects were found with the help of the Director of Army Preventive Medicine, the Medical Directorate General (Naval), and Director of Aviation Medicine, RAF. These 3 individuals and their departments wrote to various military establishments in the UK, asking for their co-operation in the survey. Once this was established the research team were informed, and subsequently made their own contacts with each Medical Officer (MO). The exact locations of each camp visited were not considered important, since members of the Forces tend to change camps approximately every 3 years and therefore do not usually come from the local area.

2.2.2. Selection from each Rank and Occupation within the 3 Services

In order to make the sample as representative of the Forces as possible, samples of approximately 2% were required from each rank in the Navy and RAF. Because of the larger numbers in the Army, however, approximately 160,000 as opposed to 72,000 and 80,000 in the Navy and RAF respectively, a sample of only about 1% was required.

Quantitative analysis was carried out on the 3 Services, both separately and together, and Appendix A, Tables 5-10 give the total numbers holding each rank, together with the numbers and percents examined in the survey. These numbers came from the following sources:

(a) 'Abstract of Army Manpower Statistics' No. 88. 1978/79.

(b) HQ Royal Air Force Support Command. Numbers as at October 1980.

(c) Royal Navy, Statistics Dept, Tavis House. Numbers as at March 1980.

The RAF and Navy samples were also analysed in trade/occupational groups, and the Army sample within each Corps/Regiment. Again an attempt was made to examine approximately 2% of each group in the Navy and RAF, and 1% in the Army. The actual selections are shown in Appendix A, Tables 11-16.

2.2.3. Subject Selection at Individual Establishments

Once the decision was made to visit an establishement, the method for selecting the subjects varied between camps. A couple of months before each visit a letter was sent to the camp Medical or Administrative Officer explaining the reasons for the survey and the measurements to be taken. This letter either came directly from the field workers, or via a district HQ. An example of a typical letter is at Appendix B. Thereafter, the organising officers arranged the selection of suitable subjects.

At the first six Service bases visited, a random sample of males and females from all ranks, ages and jobs was requested. On Table 2, this is defined as method (e). As the project progressed, however, gaps were seen in the sample, and specifications with regard to the age, trade and eventually height of the subjects had to be made. Table 2 lists the specifications used for subject selection, together with the approximate numbers of people seen using each method. An estimate of the number of subjects who were 'Asked' to attend to be measured, and the number 'Told to Attend', is also included.

These specifications were seldom strictly adhered to, but volunteers who were outwith them were still always included in the sample. The numbers are only approximate, since a mixture of methods was generally used at each establishment.

Near the start of the survey, methods (e) and (a) were most commonly used. Classes under instruction were timetabled to be measured, since the organisers at that establishement considered them to be a convenient source of large numbers of people. As gaps appeared in the sample methods (b), (c), (f) and eventually (g) were used. Throughout the survey, volunteers and 'passersby' were also included in the sample and accounted for selection methods (d) and (h).

Few subjects were pure volunteers. Most were chosen and told varying amounts about the survey before the field workers arrived. The field workers then told each subject more about the survey as he or she was being measured. As is shown in Table 2 some establishments would ask the chosen people to attend. It was found that the higher ranking and subsequently the older subjects, had most choice about attending and often had to be persuaded to become subjects.

2.2.4. Influence of the Investigators on the Sample

How much the investigators effected the attendance rate was difficult to determine. They did not choose the individual subjects but they often persuaded reluctant subjects to participate, and persuaded others to volunteer. Any person with very strong objections did not have to participate, but very few fell into this category.

2.2.5. Differences Between Those in the Sample and the Remainder of the Services

Table 5-12 in Appendix A show that the ideal samples of 2% from the Navy

Methods used for Selecting the Services Sample

Method of Selection	MALES Asked to Attend*	MALES Told to Attend	MALES Total	FEMALES Asked to Attend*	FEMALES Told to Attend	FEMALES Total
(a)	-	988	988	-	46	46
(b)(i)	-	377	377	-	-	-
(b)(ii)	580	553	1,133	29	-	29
(c)	8	90	98	-	28	28
(b) & (c) (simultaneously)	55	264	319	-	-	-
(d)	13	77	90	199	-	199
(e)	589	1,624	2,213	30	28	58
(f)	-	-	-	151	593	744
(g)	64	65	129	-	-	-
(h)	82	-	82	19	-	19
	1,391	4,038	5,429	428	695	1,123

* Approximate numbers only

KEY:

(a) Classes under instruction, timetabled to be measured as 'convenient' subjects.

(b) (i) 16 year olds, selected to be measured on the basis of their age, because the sample was lacking in that group.

(ii) Individuals over 25 years, selected to be measured on the basis of their age.

(c) Individuals selected on the basis of their trade, because the sample was lacking in that trade.

(d) Individuals from hospital staff and out-patients, when the survey was based at a hospital.

(e) Fairly random selection from all age, rank and occupational groups.

(f) Selected on the basis of sex only.

(g) Individuals selected because they were between 5ft-5ft 3ins or 6ft-6ft 3ins.

(h) Volunteers, i.e. staff, friends, wives, etc.

and RAF and 1% from the Army were not always achieved in individual groups, but were achieved overall. In general the officer ranks were not as well represented as the other ranks.

Although the numbers of females examined were low, they in fact represented a high proportion of the total numbers and overall ranged between about 5 and 10%. Once again, however, the officers and in particular the more senior officers were not as well represented as the other ranks. This is probably due to the fact that the more senior ranks seemed reluctant to be be measured.

In both sexes, most major occupational groups were sampled and although it was believed that any gaps in the sample would have little effect because of the large numbers involved, this could not be quantified.

It was thought that in general those males who were 'overweight' did not manage to avoid being subjects, and in fact were sometimes sought out specifically by those organising the flow of people. When attendance was voluntary however, it was not possible to assess whether those who did not attend were different from those who did.

The situation was slightly different with the female subjects as they always had a far greater amount of choice about attending and many although told to attend, did not. The sample may therefore have missed seeing many females who classed themselves as 'overweight'.

2.3. SUBJECT SELECTION FROM THE CIVILIAN POPULATION

2.3.1. Introduction

The aims for the civilian subjects were:

(a) To compare the anthropometric data from groups of civilians to data from similar groups in the Forces, matched for age, geographical area and/or occupation.

(b) To validate any results calculated on the Service population on a different population.

(c) To combine the 2 populations and thus increase the overall numbers, if they proved to be compatible.

2.3.2. Companies Contacted

Large companies and organisations with bases in Glasgow or Edinburgh and often in other cities throughout the UK, were contacted and their help was asked in providing male and female subjects from all age groups and jobs. About 70 Companies/Organisations were written to, and 11 agreed to help. An example of a typical introductory letter is at Appendix C.

Scottish companies were chosen mainly because it was relatively easy to see large numbers of civilians in our home area and they could then be compared with Scots in the Forces. It was also thought however, that their offices or branches through Britain could help to fill gaps in the geographical area sampling, as shown in Tables 3 and 4. Those areas from which additional sampling was most needed were

(a) London
(b) West Midlands
(c) Yorkshire and Humberside
(d) South-East England.

This idea unfortunately proved to be impracticable in most cases, because it would have necessitated covering long distances in order to see maybe only 40 people in the small subsidiary branches. In order to sample from these areas, therefore, the Medical Officers of the Civil Service, DHSS and National Coal Board were contacted, and agreed to help with the survey.

2.3.3. Subject Selection at Individual Establishments

Once the decision was made to visit a company, a few posters advertising the project, together with a few hundred questionnaires, were sent to the contact person. A reduced copy of the poster is at Appendix D. It was then left to the company to publicise the project, recruit volunteers and organise their attendance when the research team arrived.

Specifications laid down by the research team, about the type of subjects they wished, were:

(i) Females of any age but with the emphasis on those under 35 years. The reason behind this specification was that the overall sample was low in female numbers and especially those over 35 years. It was decided to concentrate on those under 35 years as it was believed that this group would be of more interest to the Services.

(ii) Males under 55 years, but with the emphasis on those outwith the height range 165 cm. - 183 cm. It was hoped that these civilians would fill up gaps in the height and age distributions of the overall male sample, if the Forces and civilian samples proved to be compatible.

(iii) At some locations, particularly the Scottish ones, males under 35 years were requested, in order to make a comparison between them and a similarly matched Forces group.

As in the case of selecting individuals from the Services, these specifications were seldom strictly adhered to, and those outside the limits were still included in the sample. The response from the civilians was completely voluntary.

2.3.4. Influence of the Investigators on the Sample

It was generally found that when there was a personal contact between one of the research team and a representative from the company being visited in order to settle various details before the visit, that company then tended to put more energy into recruiting volunteers. This was the case with the Banks, British Rail, D. Montgomery and Scottish Amicable in the Glasgow area, DHSS in London and the Civil Service in Worthing, West Sussex.

If the response rate was low when the research team arrived at a location, they increased the numbers by both personally canvassing for volunteers and asking volunteers to send along their friends. Individuals persuaded in this manner however, did not constitute a large proportion of the civilian sample, probably only approximately 5 - 10%.

2.3.5. Response Rates

Table 4, Appendix A, lists the locations and companies visited, together with the response rates. The 'Total Number' column represents the number of males or females at the individual offices or factories which were involved in the survey. It does not represent the total number of people employed by the company in the entire city. Where this figure was not known by the research team, a letter was written to the company after the visit, requesting the information. An example is shown at Appendix E. It was not possible to estimate a total number in some cases, i.e. 'MOD Civilians: Hampshire/Devon/S.W. England/Cardiff' and these response rates were therefore not calculated.

Overall, the response rate seemed to depend on the factors mentioned in the sections 2.3.4 and 2.1.

2.3.6. Differences between Volunteers and the Remainder

Although many volunteers were slim, many who were 'overweight' also volunteered. The main reasons for volunteering appeared to be:

1. A general interest in the survey.
2. A few friends volunteered, and others followed on.
3. A special interest in body composition and health, due to sporting interests or because the individual was weight conscious.

Many 'overweight' people fell into these categories, especially category 3, and the research team gave each individual an estimated 'desirable' weight.

It was not possible to give a quantitative estimation of how volunteers differed from those who did not volunteer.

2.4. ETHNIC GROUP AND GEOGRAPHICAL AREA OF THE SUBJECTS INCLUDED IN THE FINAL ANALYSIS

Although all ethnic groups were measured, only data from white Caucasians was included in the statistical analysis. Ethnic group was determined from skin colour, surname, and place of birth of parents. This methodology was adopted because there is some evidence that there are differences in body density, in the proportion of fat situated subcutaneously (Jones et al, 1977) and in fat distribution (Robson et al, 1971; Malina, 1966) between ethnic groups. It has been suggested, e.g., that Gurkhas may have higher bone densities than other Indian groups, that Indian populations when compared to Europeans may have about 15-20% more of their fat situated subcutaneously and that African, Asian and Caribbean children may have a greater proportion of their subcutaneous fat located on their trunk than on their limbs. There may also be differences in body proportions between the ethnic groups, and since all these factors combined would influence any calculated regression equations, it was considered to be more accurate if ethnic group variations were removed where possible.

2.5. GEOGRAPHICAL DISTRIBUTION OF THE FINAL SAMPLE

The Geographical Area, for each subject was defined as follows:

"The county in which the individual spent the main part of his first ten years". If he moved between several counties during the ten years, he was coded according to the country he lived in,(e.g. England or Wales) or as just 'British' if he had lived in more than one country.

Counties were then grouped into Regions, as defined by OPCS. Tables 3 and 4 give the percentage distribution of the total UK mainland population throughout these regions. These figures came from "OPCS 1979 Population Estimates, England & Wales", HMSO, and from The General Register Office for Scotland, figures as at June 1980. The total population was defined as "the population resident in England, Wales and Scotland, plus members of HM Forces serving outside England, Wales and Scotland, minus the Forces of other countries temporarily in England, Wales and Scotland". Some subjects also came from both Northern and Southern Ireland.

The tables also show the percentage distributions of both the Forces and civilian samples examined in this survey, but only those who were included in the statistical analysis. As mentioned in 2.4. some ethnic groups of small sample size were excluded from the analysis.

The geographical distribution of the total UK population, as shown in Tables 3 and 4, did not alter if the population were restricted to include

Geographical Distribution of the UK Population, Forces Sample and Civilian Sample expressed as a %

MALES

POPULATION	EIRE	NI	SCOTLAND	NORTH	YORKS & HUMBERSIDE	NORTH WEST	EAST MIDLANDS	WEST MIDLANDS	EAST ANGLIA	LONDON	SOUTH EAST	SOUTH WEST	WALES	OTHERS [1]
Total Mainland[2] UK Population	-	-	9	7	9	12	7	10	3	13	19	8	5	-
Forces Sample	0.5	2	17	6	7	9.5	6	6	2	4.5	15	9	5	6.5
Civilian Sample	0.5	0.5	41	1.5	14.5	3	4	9	0.5	6.5	12	2	1.5	3.5
Total Sample	0.5	1.5	21	5.5	8	8.5	5.5	6.5	2	5	14.5	8	4.5	6

Male Forces Sample = 5,336 (subjects included in the statistical analysis only)
Male Civilian Sample = 1,054

KEY: 1. 'Others' includes subjects from no single district, but coded as English, Welsh or British.

2. Total Mainland UK population represents the population resident in mainland UK plus members of HM Forces serving outside mainland UK, minus the Forces of other countries temporarily resident in the UK.

Figures from OPCS Population Estimates for 1979. Series PP1, No 4.

Table 4

Geographical Distribution of the UK population, Forces Sample and Civilian Sample expressed as a %

FEMALES

POPULATION	EIRE	NI	SCOTLAND	NORTH	YORKS & HUMBERSIDE	NORTH WEST	EAST MIDLANDS	WEST MIDLANDS	EAST ANGLIA	LONDON	SOUTH EAST	SOUTH WEST	WALES	OTHERS [1]
Total Mainland[2] UK Population	-	-	9	6	9	12	7	10	3	13	18	8	5	-
Forces Sample	0.5	1	10	5	10	10	7	8	1.5	2.5	13.5	9.5	5	14
Civilian Sample	1	0.1	35	1.5	17	3.5	2	5	0.4	10.5	19	1	1	3
Total Sample	0.5	0.5	23	3	13.7	6.5	4.5	6.5	1	6.5	16.5	5	3	8.5

Female Forces Sample = 1,086 (subjects included in the statistical analysis only)
Female Civilian Sample = 1,170

KEY: 1. 'Others' includes subjects from no single district, but coded as English, Welsh or British.

2. Total Mainland UK Population represents the population resident in mainland UK plus members of HM Forces serving outside mainland UK, minus the Forces of other countries temporarily resident in the UK.

Figures from OPCS Population Estimates for 1979. Series PP1 No 4.

only the age ranges examined in the present survey (i.e. 16 to 56y for the Forces and 17 to 65y for the civilians).

2.5.1. Male Samples

The Forces sample showed a disproportionally large representation from Scotland and disproportionally small samples from London, the North West, the West Midlands and the South East. Most other regions were also slightly poorly represented. The civilian sample was also biased towards Scotland for reasons explained in Section 2.3, but an attempt was made to fill in some of the gaps in the total sample distribution and this therefore influenced which civilian companies were involved in the survey. The remainder of the civilian male sample therefore came mainly from Yorkshire & Humberside, the West Midlands, London and the South East.

The overall male sample was therefore over representative of Scotland, 21% as opposed to 9% and under representative of London, 5% as opposed to 13%. The South East, West Midlands and North West were also obviously under represented.

2.5.2. Female Samples

The main deficiencies in the Forces female sample, were the disproportionally small samples from London and the South East. The civilians were again over-sampled in Scotland, with the remainder of the sample coming mainly from Yorkshire & Humberside, the West Midlands, London and the South East.

The overall female sample was over-representative of Scotland with 23% as opposed to 9%, and Yorkshire & Humberside with 13.7% as opposed to 9% in the general population. It was under-representative of most other regions, but in particular the North, the North West and London.

These biases within the male and female samples were not considered to be of great importance since the geographical area analysis in Chapter 3 showed only small differences in the anthropometric measurements between the regions.

2.6. FIELD METHODS FOR ASSESSING 'OVERWEIGHT'

2.6.1. 'Desirable Weight for Height' Charts

(a) Metropolitan Life Insurance Company of New York

In 1959, as a result of growing concern about body weight and longevity, and after the completion of the American Society of Actuaries Build and Blood Pressure Study (1959), the Metropolitan Life Insurance Company published an important Statistical Bulletin. This bulletin, using the results from the actuarial study, included tables of average heights and weights for age for men and women, together with revised standards of 'desirable' weights. The figures for 'Desirable Weights' are shown in Table 5. Claiming to assess 'fatness', these tables are often used not only in population studies, but also by doctors advising patients, or by individuals anxious about their own weight.

The Build and Blood Pressure Study had covered several million people insured by 26 large Life Insurance companies in the USA and Canada during the period 1935-53. On re-examining the data in 1959 however, the Society of Actuaries noted that a maximum of 80% of the weights recorded were actual measurements, and that the applicants were dressed in indoor clothing, including shoes. There was also no means by which the actuaries could assess how many of the weights had been falsified, or how representative of the total population their sample was.

The Metropolitan Life Insurance Company however, produced in 1959 modified tables of 'desirable' weights for both men and women. The actuaries acknowledged that there was no single, 'desirable' weight for all individuals of the same height, due to differences in bone and muscle bulk. They therefore assumed that the weight range at each height for those in their early 20s was 'desirable' and split these ranges into thirds. The average weight in each third was then quoted as 'desirable' for small, medium and large frames, respectively. No increase in weight was allowed for increasing age.

Unfortunately, since no measure of 'frame' was taken when these tables were

DESIRABLE WEIGHTS FOR MEN AND WOMEN

According to Height and Frame. Ages 25 and over.

Height (in Shoes)	WEIGHT IN POUNDS (In Indoor Clothing)		
	Small Frame	Medium Frame	Large Frame
	MEN		
5' 2"	112–120	118–129	126–141
3"	115–123	121–133	129–144
4"	118–126	124–136	132–148
5"	121–129	127–139	135–152
6"	124–133	130–143	138–156
7"	128–137	134–147	142–161
8"	132–141	138–152	147–166
9"	136–145	142–154	151–170
10"	140–150	146–160	155–174
11"	144–154	150–165	159–179
6' 0"	148–158	154–170	164–184
1"	152–162	158–175	168–189
2"	156–167	162–180	173–194
3"	160–171	167–185	178–199
4"	164–175	172–190	182–204
	WOMEN		
4'10"	92– 98	96–107	104–119
11"	94–101	98–110	106–122
5' 0"	96–104	101–113	109–125
1"	99–107	104–116	112–128
2"	102–110	107–119	115–131
3"	105–113	110–122	118–134
4"	108–116	113–126	121–138
5"	111–119	116–130	125–142
6"	114–123	120–135	129–146
7"	118–127	124–139	133–150
8"	122–131	128–143	137–154
9"	126–135	132–147	141–158
10"	130–140	136–151	145–163
11"	134–144	140–155	149–168
6' 0"	138–148	144–159	153–173

NOTE: Prepared by the Metropolitan Life Insurance Company. Derived primarily from data of the 'Build and Blood Pressure Study', 1959, Society of Actuaries.

produced, subjective impressions have to be relied upon. Since the range of 'desirable' weights at any one height extends over 30-40lbs (approximately 14-18kg) in males and 28-36lbs (approximately 13-16kg) in females, there is a large scope for error if the wrong 'frame' category is chosen.

Using data from these life insurance tables, Relative Weight is often calculated and used as a measure of obesity.

$$\text{Relative Weight} = \frac{(\text{Actual Weight})}{(\text{Desirable Weight})} \times 100$$

This method however, emphasises another 2 major drawbacks of the tables. First of all, they are based on average values and averages are likely to vary with time both within and between populations. The average fat content associated with average weight, is not necessarily 'desirable', especially in the developed countries and therefore averages are fairly arbitrary and very sample-dependent. The second drawback is that results calculated from an American population should not, theoretically, necessarily be considered applicable to a British population, although these Insurance Company results have been applied in British studies because of a lack of any similar British standard.

(b) British Army Guide to Desirable Weights

Because of the lack of a similar large-scale British study relating mortality and weight, most British tables of 'Desirable Weights' have been based on the American data, with various modifications added. The standard Army guide to desirable weights (Table 6) is no exception.

The American tables relate to individuals in indoor clothing and wearing shoes, and therefore in calculating suitable, nude, 'desirable' weights, subtractions of approximately 1" and 7 lbs. were made to each height and frame group in the male results, and 2" and 5 lbs. to most groups in the female results. Thus modified, the maximum weight in each American height and frame group was then taken as the desirable weight for the British tables, and a conversion to metric units made.

The calculation of the maximum permitted weight in each group was slightly

MAXIMUM BODY WEIGHTS - MEN

Metric Units (cm and kg)

Height cm	Small Frame		Medium Frame		Large Frame	
	Desirable	Permitted	Desirable	Permitted	Desirable	Permitted
152	49.0	59.0	54.0	65.0	59.0	71.0
154	50.5	60.5	55.5	66.0	60.5	72.5
156	51.5	62.0	56.5	67.5	61.0	73.5
158	52.5	63.0	57.5	69.0	62.5	75.5
160	54.0	65.0	58.5	70.5	64.0	76.5
162	55.5	66.0	60.0	71.5	66.0	79.0
164	56.5	68.0	61.0	73.5	67.0	80.5
166	58.0	70.0	62.5	75.5	68.5	82.0
168	59.5	71.0	64.0	76.5	70.0	84.0
170	61.0	73.0	65.5	78.5	71.5	86.0
172	62.0	74.5	66.5	80.0	73.0	87.5
174	63.5	76.0	68.5	82.0	75.0	90.0
176	65.0	78.0	70.0	84.0	76.5	92.0
178	66.5	80.0	71.5	86.0	78.0	93.5
180	68.0	81.5	73.5	88.0	80.0	95.5
182	70.0	84.0	75.5	90.5	81.5	98.0
184	71.0	85.5	77.0	92.5	83.5	100.0
186	73.0	87.5	79.0	95.0	85.5	102.5
188	75.0	90.0	81.0	97.5	87.0	104.5
Obesity Index (Averaged) $\frac{Wt\ (kg)}{Ht\ (m)^2}$	21.0	25.2	22.6	27.2	24.7	29.6

MAXIMUM BODY WEIGHTS - WOMEN

Table 6

Metric Units (cm and kg)

Height cm	Small Frame		Medium Frame		Large Frame	
	Desirable	Permitted	Desirable	Permitted	Desirable	Permitted
146	44.0	52.5	47.5	57.0	53.5	64.5
148	45.5	54.5	49.0	59.0	55.0	66.0
150	46.5	55.5	50.5	60.5	56.0	67.0
152	47.0	56.5	51.5	62.0	57.0	68.5
154	48.5	58.0	53.0	63.5	58.0	70.0
156	49.5	59.5	54.5	65.5	59.5	71.0
158	51.0	61.0	56.0	67.0	61.0	73.0
160	52.0	62.5	57.0	68.5	62.0	74.5
162	53.5	64.5	58.5	70.5	63.5	76.0
164	54.5	65.5	60.0	71.5	65.0	78.0
166	56.0	67.0	61.0	73.5	66.0	79.5
168	57.5	69.0	62.5	75.5	68.0	81.5
170	59.0	71.0	64.0	76.5	69.5	83.5
172	60.5	72.5	65.5	78.5	71.0	85.5
174	61.5	74.0	67.0	80.5	72.5	87.0
176	63.5	76.0	68.5	82.0	74.5	89.5
178	65.0	78.0	70.0	84.0	76.0	91.5
180	66.5	80.0	71.5	86.0	78.0	93.5
182	68.5	82.0	73.0	87.5	80.0	95.5
184	70.0	84.0	74.5	89.5	82.0	98.5
Obesity Index (Averaged) $\frac{Wt\ (kg)}{Ht\ (m)^2}$	20.4	24.5	22.3	26.8	24.5	29.4

Taken from 'Army Medical Directorate Bulletin', Third Series, No2, June 1978.

less obvious. It was defined as 120% of the desirable weight, since it was proposed that this would constitute an unacceptable degree of obesity in most people (Crowdy 1978).

An immediate limitation of these tables is obvious. For any height range of 2cm, there is a permitted weight range which includes all 3 'frame' categories, of 22 to 29kg in both males and females. Even within one 'frame' category the range from 'desired' to 'permitted' weight is anything between 10kg and 17kg.

Assuming that a specified 'desirable' weight represents about 15% body fat for a male, these wide ranges mean that even if he was subjectively put into a suitable 'frame' category, his fat content could increase to about 29%, a totally 'undesirable' level, before he exceeded his permitted weight. If the frame category was incorrectly assessed, i.e. 'large' instead of 'medium' or 'medium' instead of 'small', his percent fat could reach about 34%. On the other hand, if he was above average build and in the 'large' frame category, the 'desirable' weight could be unhealthily thin, and 'permitted' only slightly plump. There is an obvious lack of accuracy and dependence on subjective impressions in these tables.

Other limiting factors to their use are as described in Section 2.6.1.(a), that not only are they based on American populations, and parallels cannot necessarily be drawn between populations, but they are also based on averages. The 1959 insurance tables were modified from those produced in 1943 because of the updated height and weight data. This shows that they tend to reflect the state of the population at that time, and there is no accurate method for assessing what that state was, in terms of 'fatness' levels.

More recent actuarial studies on both American populations (Framingham study) and European populations (Rose et al, 1977) have differed in their conclusions from those of the Metropolitan Life Insurance Company which had stated that 'lowest mortality generally occurs among people who are well below average weight'. The opposite is in fact now being suggested, and lowest mortality is suggested to occur in those just over average weight, with rising risk both above and below this figure. If this is in fact true, then Weight for Height tables which encourage low weights and allow no increase in weight with age may not provide healthy guidelines.

2.6.2. The Quetelet Index - Introduction

Many small as well as large scale studies in the nutritional and epidemiological fields use Height-Weight indices as convenient indicators of obesity. Some examples are W/H, W/H^3, $W^{0.33}/H$, W:'Desirable W' and W/H^2, the Quetelet Index.

The important characteristics of a good index are that it must correlate fairly highly with weight and percent fat, but must show little association with height. In general, it is accepted that the best index fulfilling there prerequisites in populations over 16 years is $W:H^2$ (Billewicz et al 1962; Womersley et al 1977; Roche et al 1981), although some investigators have found that W:H shows less association with height than $W:H^2$ Watson et al (1979) and Lee et al (1981) advocate that c/H^P, where p could vary according to the population, is a more suitable index in populations of mixed ethnic groups.

Tables 7 and 8 summarise the results of several studies, showing the correlations between $W:H^2$ and height, weight and 'fatness' as measured by densitometry, skinfold measurements or total body water calculations. In all studies except Womersley et al (1977), the correlation between the index and height was less than or equal to 0.2. Where quoted, the correlation with weight was about 0.8. Many studies, however, have shown the index to have higher correlations with weight than 'fatness' (Watson et al 1979; Goldbourt et al 1974), which indicates that weight may have a greater effect on the index than fatness, and supports the idea that the index cannot differentiate between weight due to muscle, bone or fat. (Norgan and Ferro-Luzzi, 1982).

The objectives of this section were therefore:

1. To look at the relationship between W/H^2 and height, weight, and 'fatness' as calculated from 4 skinfold measurements, in a sample of 5,072 males between 16 and 56 years and 1,007 females between 17 and 34 years.

2. To examine the limitations of the index by looking at

(a) the variations in W/H^2 within groups of limited body fat content,

Table 7

Correlation between W/H^2 and Height, Weight and % Fat in Various Studies

MALES

Study	Subjects	Age	n	Ht (cm)	Wt (kg)	Fat Calculated From: Density	Body H_2O	4 Skinfolds
Allen et al (1956)	Chinese	-	55	0.16		0.80		
Keys et al (1972)	USA - Students		180	0.02		0.85		
	USA - Executives		249	0.06		0.67		
Watson et al (1969)	American	Adults	477	-0.20	0.80		0.55	
Brockett et al (1956)	American Army	Young Men	97	-0.08		0.60		
Womersley & Durnin (1977)	British	17-19 y	28	0.23		0.49*		
		20-29 y	112	-0.15		0.55		
		30-39 y	38	-0.40		0.56		
		40-49 y	37	-0.36		0.62		
		> 50 y	30	-0.14		0.53		
Norgan & Ferro - Luzzi (1982)	Italian	22-55 y	138	0.07		0.75		
Present Study	British	16 y	370		0.77			0.61*
		17-19 y	1,036	Range	0.81			0.72
		20-24	1,204	-0.12	0.83			0.76
		25-29	760		0.84			0.75
		30-34	692	to	0.84			0.75
		35-39	550	0.09	0.83			0.74
		40-44	261		0.84			0.73
		45-49	143		0.82			0.68
		50-56	66		0.86			0.74

* Spearman Rank Correlation

Table 8

Correlation between W/H^2 and Height, Weight and % Fat in Various Studies

FEMALES

Study	Subjects	Age	n	Ht (cm)	Wt (kg)	Fat Calculated From: Density	Body H_2O	4 Skinfolds
Allen et al (1956)	Chinese	-	26	0.03		0.72		
Watson et al (1969)	American	Adults	301	-0.173	0.93		0.70	
Womersley & Durnin (1977)	British	17-19	32	0.22		0.64*		
		20-29	114	-0.06		0.71		
		30-39	71	-0.11		0.91		
		40-49	55	-0.13		0.84		
		> 50	52	-0.14		0.88		
Present Study	British	17-19	399	Range	0.82			0.76*
		20-24	469	-0.096	0.81			0.77
		25-29	105	to	0.83			0.73
		30-34	35	0.129	0.86			0.71

* Spearman Rank Correlation

(b) variations in Fat Free Mass within limited height and weight ranges.

(a) Relationship between the Quetelet Index and weight, height and percent fat in age groups. From the results of Womersley and Durnin (1977) and Norgan and Ferro-Luzzi (1982), it seem probable that the relationship between W/H^2 and 'fatness' may be dependent on the average age of the individuals being examined. This may explain, to some extent, the variations in correlations found by different workers when studying this relationship. In this study, therefore, the subjects were divided according to their age, and the results are shown in Tables 9(a) and 9(b).

The correlations between the Index and Height, Weight, Percent Fat, and FFM are presented in Tables 7,8 and 10 with the Residual Standard Errors (RSE) in Tables 10(a) and 10(b).

In agreement with most other workers, this study found a low correlation between W/H^2 and Height in both sexes and all age groups, with values ranging from -0.12 to 0.13.

Examining the relationships between W/H^2, percent fat and weight, Table 9(a) and Graph 6(a), Section 3.2.1. tend to suggest that in males the changes in W/H^2 reflect changes in mean weight more than mean fat content. Whereas percent fat seemed to increase at a fairly steep gradient throughout all the age groups, both weight and W/H^2 had steeper gradients before the 25-29y group than after. Because of low numbers in each age group, no such interpretation could be made from the female results on Table 9(b) or Graph 6(b).

Tables 10(a) and 10(b) analyse these relationships in quantative terms. Only female results between the ages of 17 and 34 years were analysed because of the low sample sizes outwith that range. In all age groups and both sexes the correlations between weight and W/H^2 were higher than those between percent fat and W/H^2. The Residual SEs which are lower in the W/H^2 to weight regression, also reflected the closer relationship between these two variables. Because of the positive skew in the distribution of percent fat, the Spearman Rank correlation was calculated between W/H^2 and percent fat, but the difference between this and the standard correlations were minimal. All residual standard errors were calculated from regression

Description of 5072 Male & 1043 Female Forces Personnel

Table 9(a)

Males: n = 5072

Age Group	n	Mean Weight (kg)	SD	Mean % Fat	SD	Mean Height (cm)	SD	Mean FFM (kg)	SD	Mean W/H^2	SD
16yrs	370	65.5	7.8	13.4	3.2	174.8	6.6	56.5	5.8	21.4	2.0
17-19	1,036	68.0	9.0	15.4	4.1	175.5	6.7	57.6	6.1	22.1	2.3
20-24	1,204	72.4	9.8	16.6	4.7	176.0	6.6	60.4	6.3	23.4	2.8
25-29	760	75.1	11.3	17.4	4.6	176.2	7.1	62.0	7.2	24.2	3.0
30-34	692	76.5	10.8	21.1	3.8	175.6	6.4	60.4	6.5	24.8	2.9
35-39	550	76.9	10.6	21.1	3.7	175.6	6.6	60.7	6.7	24.9	3.0
40-44	262	78.2	11.0	24.5	4.6	175.4	6.6	59.0	6.4	25.4	2.8
45-49	142	80.3	10.1	25.5	4.3	176.5	6.3	59.6	6.0	25.7	2.8
50-56	66	80.0	12.7	27.2	5.3	175.3	7.2	57.7	6.6	25.9	3.3

Table 9(b)

Females: n = 1007

Age Group	n	Mean Weight (kg)	SD	Mean % Fat	SD	Mean Height (cm)	SD	Mean FFM (kg)	SD	Mean W/H^2	SD
17-19	399	60.5	8.0	28.0	3.9	163.2	6.1	43.3	4.5	22.7	2.5
20-24	469	61.4	8.7	28.1	4.5	164.1	6.8	43.9	4.7	22.8	2.8
25-29	104	60.7	9.3	27.2	5.0	163.9	6.9	43.8	5.0	22.5	2.9
30-34	35	58.9	7.7	29.8	3.6	160.1	5.3	41.1	4.0	22.9	2.3

Correlation between W/H^2 and % Fat, Weight and FFM

Table 10(a)

Males: n = 5072

Age Group	n	% Fat - W/H^2 r	Residual SE (x on y)	Wt - W/H^2 r	Residual SE (x on y)	FFM - W/H^2 r	Residual SE (x on y)
16 yrs	370	0.66	22	0.77	16	0.65	22
17-19	1036	0.76	23	0.81	18	0.65	31
20-24	1204	0.78	30	0.83	24	0.64	46
25-29	760	0.76	38	0.84	26	0.69	48
30-34	692	0.76	37	0.84	26	0.71	44
35-39	550	0.75	39	0.83	27	0.70	45
40-44	262	0.74	36	0.84	24	0.65	46
45-49	142	0.66	46	0.82	27	0.64	48
> 50y	66	0.82	37	0.86	30	0.61	71
16-59y	5072	0.78	36	0.86	24	0.66	52

Table 10(b)

Females: n = 1043

Age Group	n	% Fat - W/H^2 r	Residual SE (x on y)	Wt - W/H^2 r	Residual SE (x on y)	FFM - W/H^2 r	Residual SE (x on y)
17-19	399	0.76	28	0.82	21	0.64	38
20-24	469	0.77	31	0.81	26	0.58	51
25-29	104	0.70	45	0.83	28	0.62	56
30-34	35	0.76	24	0.86	15	0.73	27
17-54	1043	0.76	32	0.82	25	0.60	49

Note:

(i) % Fat calculated from Σ 4 skinfolds
(ii) All Residual Standard Errors have been multiplied by 10-1
(iii) Female age groups beyond 34 years were not included because of low values of n

predictions of W/H^2 with the second variable, and were therefore comparable between both the rows and columns in Table 10.

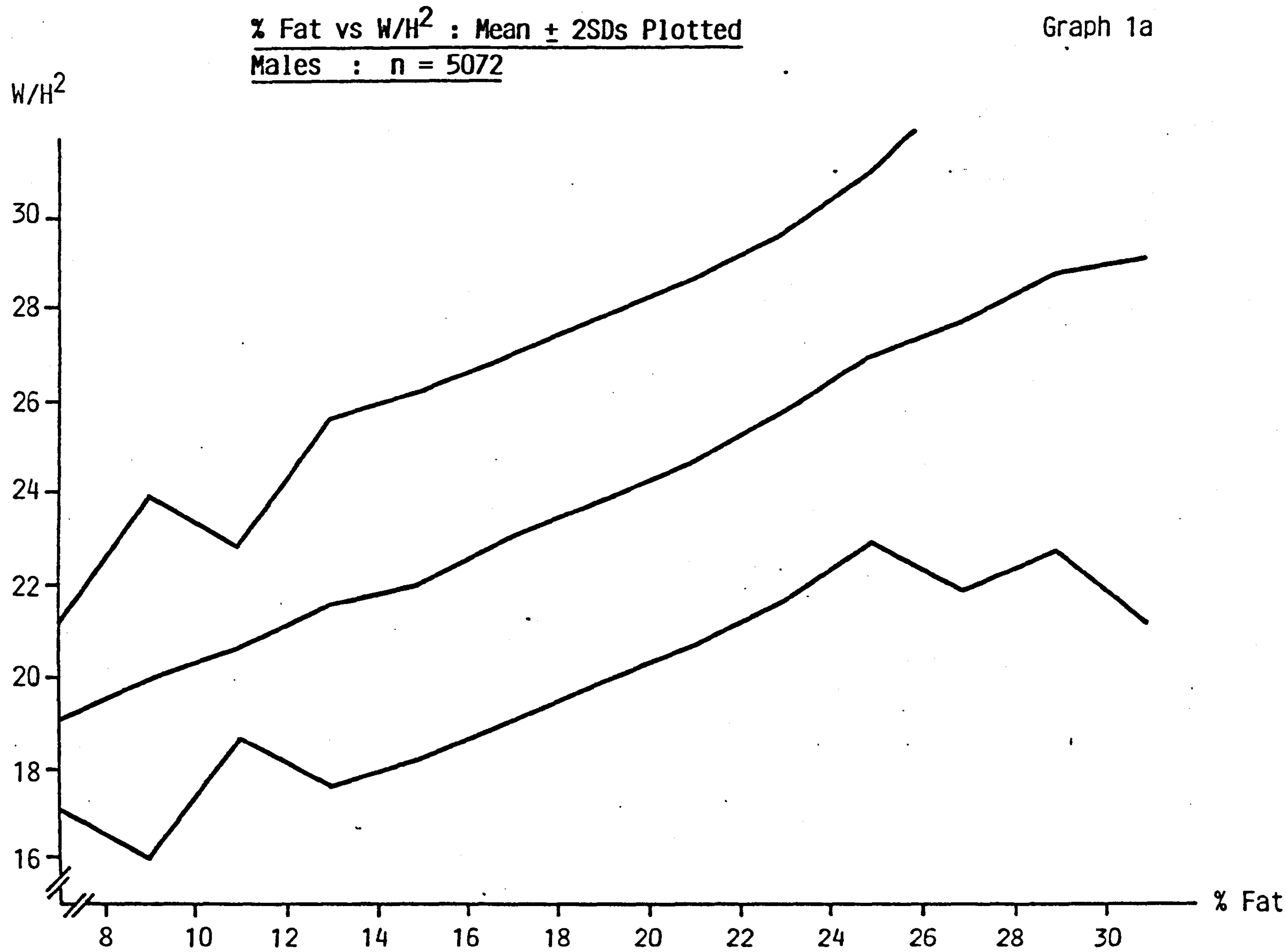
The regression of W/H^2 with FFM gave a lower correlation coefficient and higher RSE in all age groups, when compared to the W/H^2 to percent fat regression, demonstrating that W/H^2 is a better indicator of 'fatness' than of FFM.

The pattern of these results tends to agree with those of most other similar studies, as summarised in Tables 7 and 8. Correlation coefficients were close to those of Allan et al (1956) and Keys et al (1972) and higher than those of Watson et al (1969) and Womersley et al (1977). It is difficult, however, to make a direct comparison, because of the different methods used to assess fat contents and the need to compare RSE's as well as the correlation coefficients. In agreement with those studies however, we found a greater relationship between W/H^2 and weight, than between W/H^2 and percent fat (calculated from skinfolds) in all age groups examined.

(b) Variations in the Quetelet Index within limited percent body fat groups. 5,072 males and 1,007 females from the Forces sample were divided into groups according to their fat content, each group having a range of 2%. The mean and twice the Standard Deviation (SD) of the Quetelet Index were calculated for each group, and plotted against fat content. Graphs 1a and 1b depict 3 lines, representing the (mean), (mean + 2SD) and (mean - 2SD), therefore 95% of the same population would fall within the 2 outer lines.

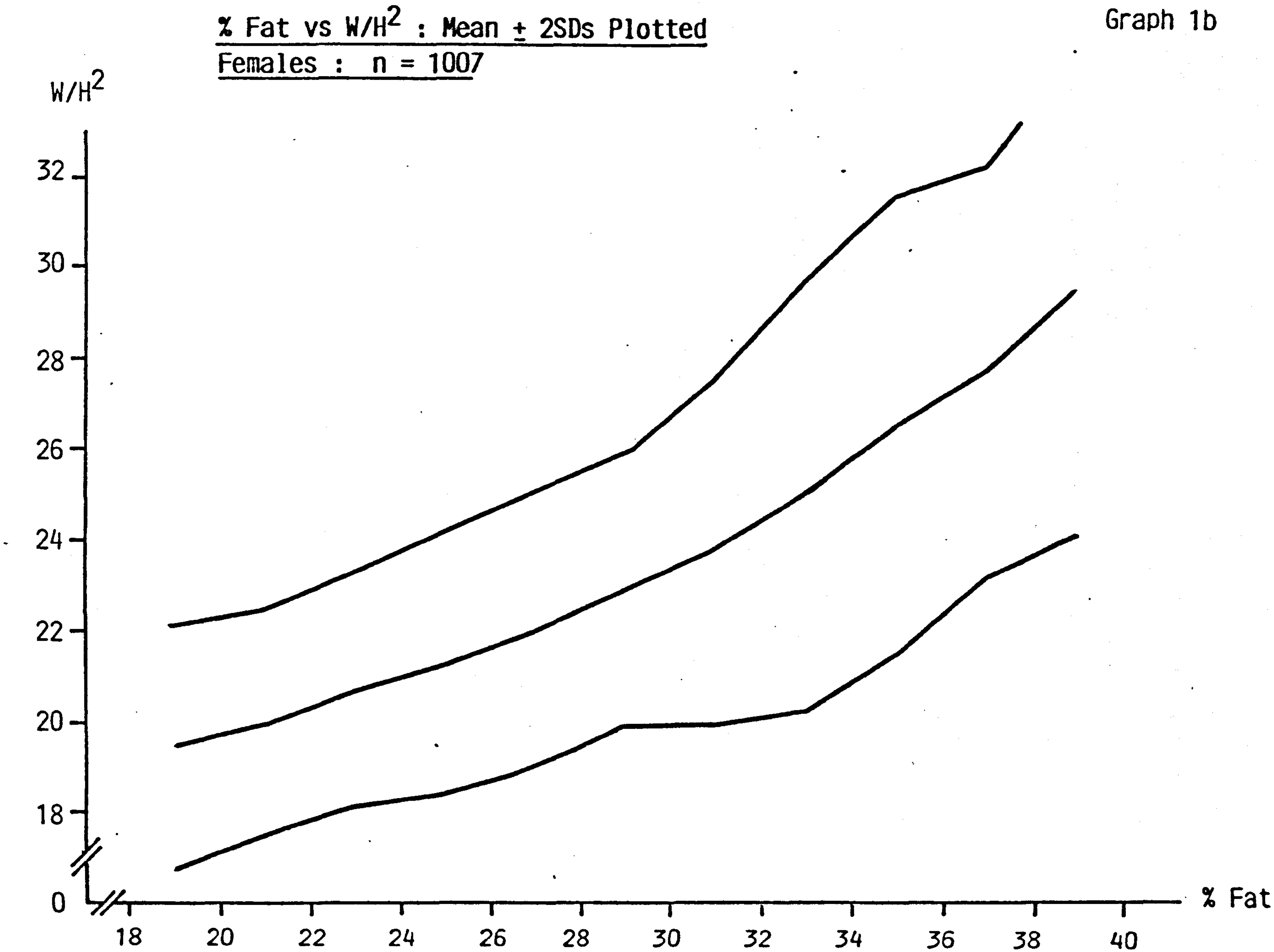
These graphs show that at any fat content, there is a large range of possible values for W/H^2, e.g. in the male group with fat contents between (14-16)% the W/H^2 range extended from 18-26. This range width was maintained at all levels of fat content, except for a slight inward kink in the (10-12)% fat group, and a slight widening at fat levels over 26%. In the female sample, those subjects with fat contents between 24 and 26% had a range of W/H^2 from about 18 to 24. This range width was about 5 W/H^2 units among subjects with fat contents below 25% and increased gradually to about 10 units by 35% fat. This increased variability suggests that the index may be of more value in 'slim' than in 'over fat' females. If age was taken into account, it was found that each value of W/H^2 tended to

Graph 1a



% Fat vs W/H2 : Mean ± 2SDs Plotted
Males : n = 5072
W/H2
30
28
26
24
22
20
18
16
% Fat
8
10
12
14
16
18
20
22
24
26
28
30

Graph 1b


% Fat vs W/H2 : Mean ± 2SDs Plotted
Females : n = 1007
W/H2
32
30
28
26
24
22
20
18
0
18
20
22
24
26
28
30
32
34
36
38
40
% Fat

represent the lower fat contents in the younger groups and higher fat contents in the older groups, but a wide range still existed.

Similarly, the ranges of W/H^2 commonly accepted as representing desirable norms for individuals of about average frame i.e. 21-23 in males, and 20-22.5 in females. (DHSS/MRC 1976), did not in fact include only 'slim' individuals.

From the graphs, these values represented wide ranges of fat content, from approximately 8% to 25% in males, and 19% to 36% in females. It becomes obvious, therefore, that W/H^2 is of very limited use as an index of fat content or obesity, at least in individuals.

(c) Variations in FFM and W/H^2 within limited height and weight ranges. FFM was calculated for each subject in the sample.

$$FFM = Weight - (\frac{\% Fat}{100} \times Weight)$$

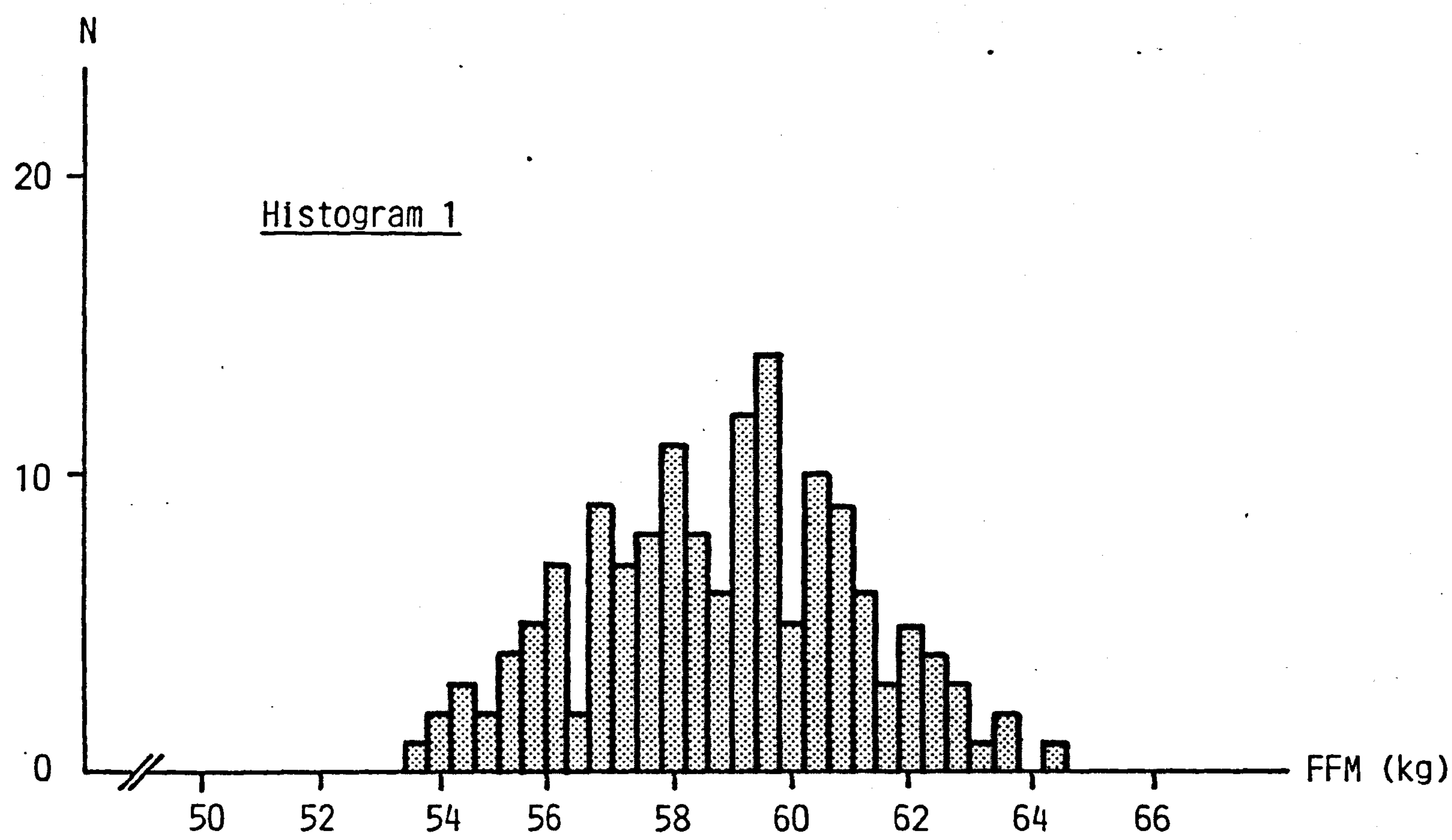
In order to look at the variation in FFM within a limited height and weight range similar to the type found in the 'Desirable Weight' tables, males of height 175-179.9cm and females between 160-164.9cm were selected. Within these height ranges, males were further selected in the weight ranges (i) 62-63.9kg (ii) 70-71.9kg (iii) 80-81.9kg and females in the ranges (i) 54-55.9kg (ii) 60-61.9kg (iii) 64-65.9kg. Histograms were plotted, as shown in Graphs 2 to 5, (histograms 1-8). A description of the subjects is given in Table 11.

(i) Males

It was seen from Histograms 1 to 3 that although weight only varied by 2kg and height by 5cm in any one group, FFM had a variance of approximately 10kg in each of the 3 groups. The index W/H^2 had a maximum range of 2, found in the 80-81.9kg group, but those individuals with the lower values of W/H^2 were not necessarily those with the smallest values for percent fat. By measuring height and weight alone, there was no way of differentiating between those at the right of the FFM histograms, who were lean, or those at the left side who were fat.

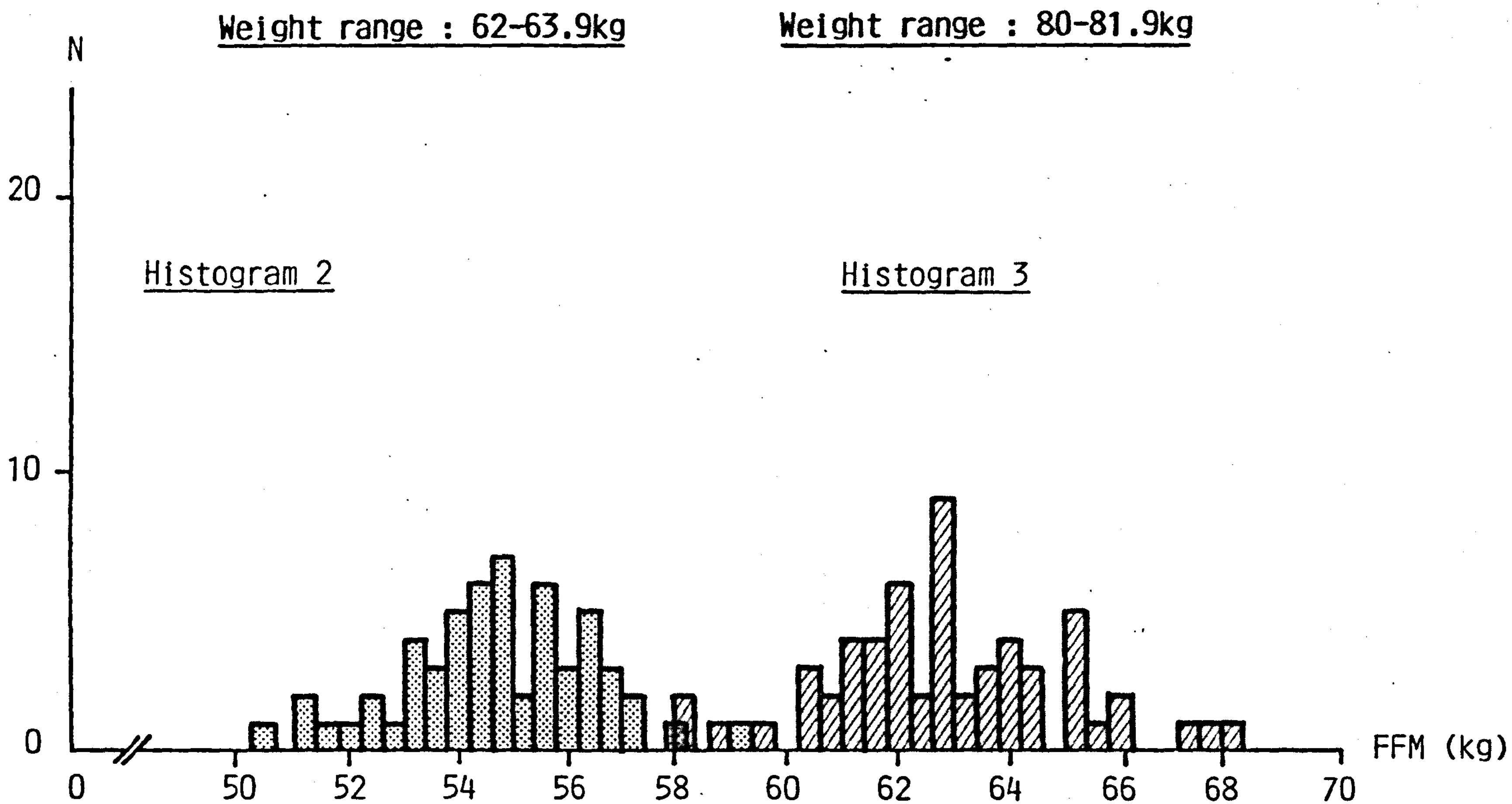
Graph 2a

Histogram of FFM for Males
of Weight : 70-71.9kg.   Height 175-179.9cm   (n = 150)



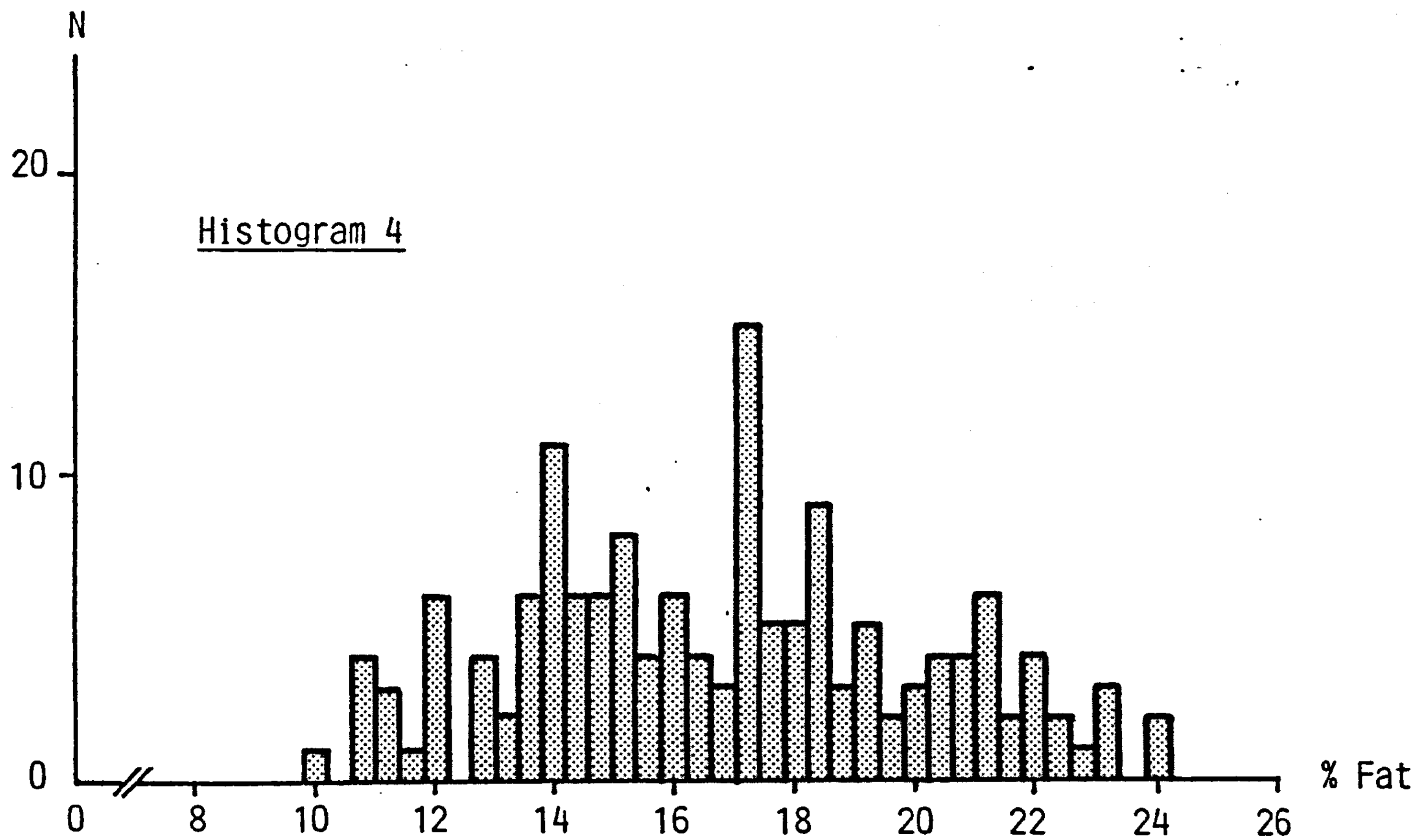
Histograms of FFM for Males of Height 175-179.9cm

Graph 2b

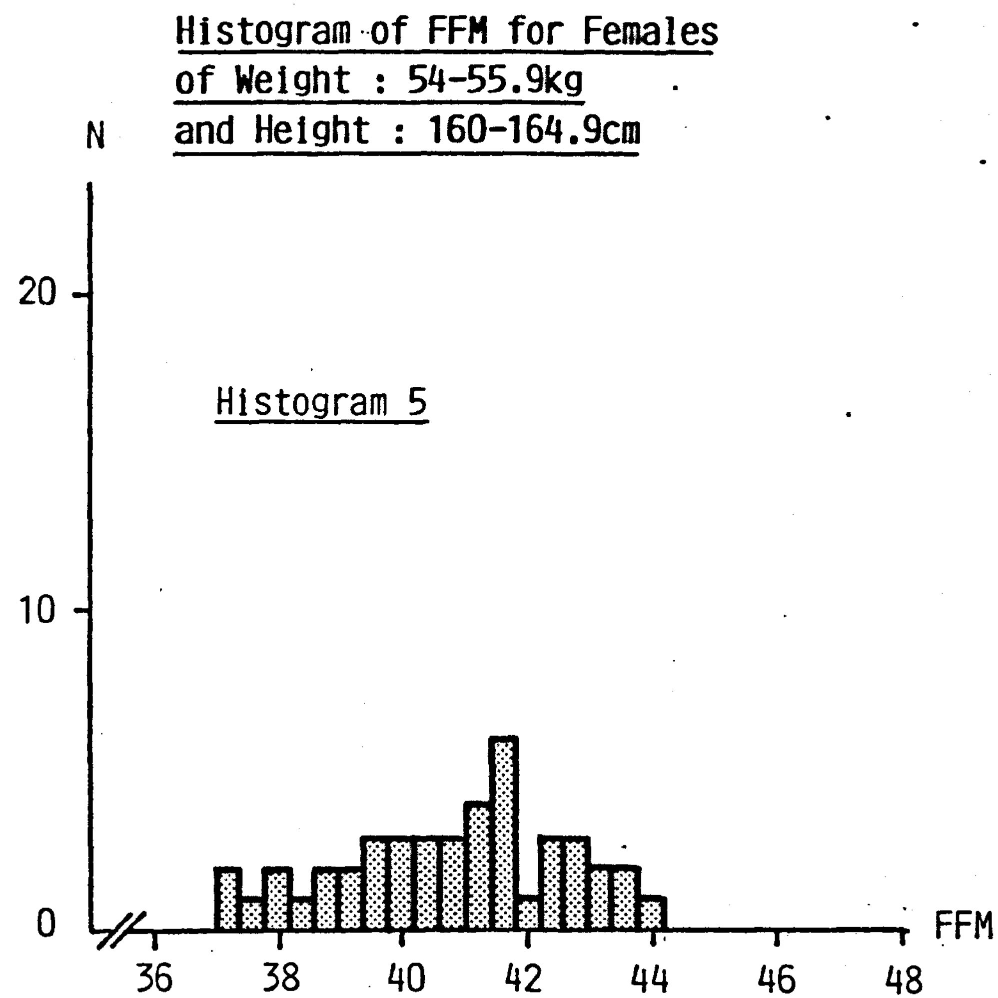


Graph 3

Histogram of Percent Body Fat for Males
of Weight : 70-71.9kg. Height : 175-179.9cm (n = 150)



Graph 4a

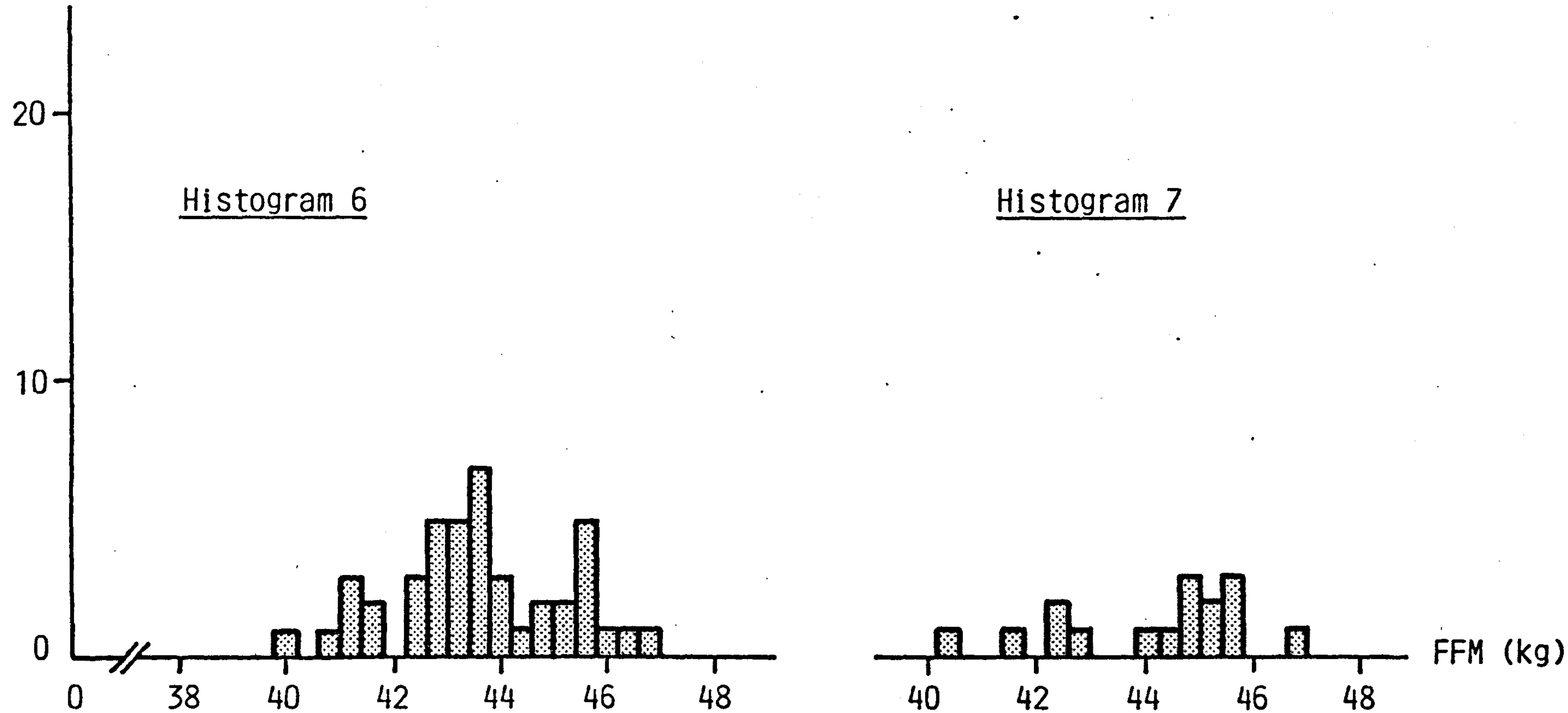


Histogram of FFM for Females
of Weight : 54-55.9kg
and Height : 160-164.9cm
N
20
10
0
Histogram 5
FFM
36
38
40
42
44
46
48

Graph 4b

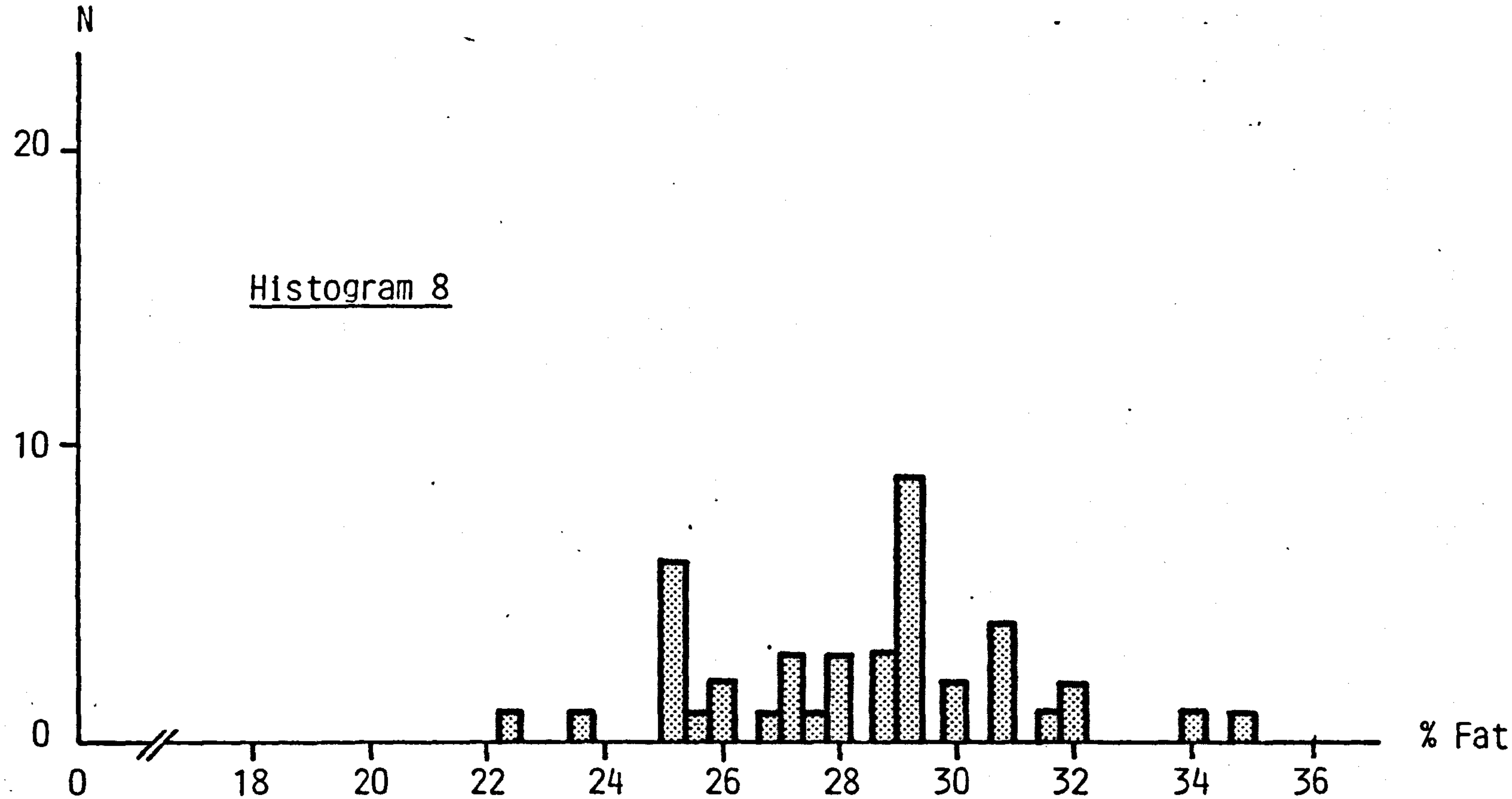
Histogram of FFM for Females of Weight : 60-61.9kg and Height : 160-164.9cm

Histogram of FFM for Females of Weight : 64-65.9kg and Height : 160-164.9cm



Graph 5

Histogram of Percent Body Fat for Females
of Weight : 60-61.9kg. Height : 160-164.9cm (n = 43)



Descriptions of Subjects (Male and Female), divided according to their Weight

Males

Variables	62-63.9kg Group 1	70-71-9kg Group 2	80-81.9kg Group 3
n	56	150	57
Mean Percent Fat	13%	17%	22%
Mean FFM (kg)	54.7	58.8	62.9
SD	1.76	2.3	2.14
Max Range for W/H^2	19.2-20.9	21.6-23.5	24.7-26.7

Ages ranged from 17-55 years. All subjects were in the ht range 175-179.9cm.

Females

Variables	54-55.9kg Group 1	60-61.9kg Group 2	64-65.9kg Group 3
n	44	43	16
Mean Percent Fat	26%	28%	32%
Mean FFM	40.8	43.6	44.1
SD	1.8	1.57	1.72
Max Range for W/H^2	19.8-21.8	22.0-24.2	23.5-25.7

Ages ranged from 17-34 years. All subjects were in the ht range 160-164.9cm.

To further demonstrate this fact, taking the W/H^2 range (21-23) which is often considered to be desirable in males, then all subjects in the 2nd group were too light, and in the 3rd group too heavy. Those individuals at the top end of the 3rd histogram and bottom end of the 2nd histogram, however, had similar fat contents of about 18%, but their different 'builds' had given them different W/H^2 values.

The average fat content in the 70-71.9kg male group was 16.6 $\pm$ 3.4% (Graph 3, Histogram 4). Although this group had a generally acceptable range of Quetelet Indices, from 21.6 to 23.5, 17% had fat contents over 20%, which could be considered far from 'desirable'.

The index therefore, did not differentiate between the fat and FFM components of weight.

(ii) Females

Histograms 5-7 show that within a 5cm height range and 2kg weight range, FFM varied by about 7kg, with 95% of each sample lying within approximately $\pm$ 3kg of their respective means. Within each group, however, the Quetelet Index had a maximum range of only 2.2 units and therefore was not differentiating between individuals on the left side of the histogram, with relatively high fat contents, and those on the right side with relatively low fat contents. These results are similar to those found in the male sample.

The average fat content in the 60-61.9kg female group was 28.4% with a SD of 2.6%. The distribution of fat contents in this group was shown on Histogram 8 and had a range from 21% to 33%, while W/H^2 only varied by 2.2 units. Again, therefore, the index did not differentiate between the fat and FFM components of weight, and there was a wide range of both variables for only a small range in W/H^2.

(d) 'Recommended' W/H^2 Ranges. In conclusion therefore, from the possible field methods mentioned in this report for assessing fat content, the most popular is probably W/H^2, because of both its simplicity and its independence from complex reference standards. This index can be of value in population studies where the aim is to assess groups of people, but at the individual level, as shown above, it is not sufficiently sensitive and both age and 'build' apparently require to be taken into account.

Possible ranges of 'desirable' W/H^2 values have been suggested by various studies. Garrow (1981) after examining mortality figures, suggested 4 'obesity' groups;

Grade 0: W/H^2 20-24

Grade 1: W/H^2 25-29

Grade 2: W/H^2 30-39

Grade 3: $W/H^2 > 40$

Grade 0 is classed as non-obese and therefore 'desirable' while group 3 is exceedingly obese but no age or 'build' factors are included.

A British report however, published by the DHSS/MRC Group on Research on Obesity (1976), suggested alternative ranges based on the 'Desirable' weights for height given by the Metropolitan Life Assurance Company.

'Desirable' Ranges of W/H^2 for Males and Females — Table 11b

	Small Frame	Medium Frame	Large Frame
Men	19.7-21.2	20.7-22.9	22.1-24.9
Women	19.1-20.6	20.1-22.5	21.4-24.6

These ranges have 'build' categories, but they rely on subjective as opposed to quantative categorisation.

In some aspects these 2 studies are in agreement, since all the 'Desirable' ranges in the latter study fit into the 'non-obese' range in the former study. On the other hand, Garrow quoted very wide ranges because he was trying to assess 'obesity' while the DHSS/MRC group were attempting to assess 'desirable' W/H^2 ranges based on an underlying assumption that this would reflect some 'desirable' fat content. Within Garrow's range of 20-24 not all the individuals would be classed as having 'desirable' fat contents, but it was estimated that at least most of them would not be 'obese'. These studies therefore raise the question about how much accuracy can be gained from W/H^2 i.e. should the wide range suggested by

Garrow or the more narrow ranges suggested by the DHSS/MRC group be used? The narrow ranges of course cannot be as accurate as they appear simply because a subjective impression of 'frame' is required initially. The analyses in the next sections were carried out in order to try and answer this question.

(i) 'Build' Categories when using the Quetelet Index

Males

The male subjects were divided into 9 age groups, and within each group the subjects who fell within the 3 W/H^2 ranges suggested by the DHSS/MRC group were selected and their fat contents are shown in Table 12(a).

These categories were suggested as a method for taking into account 'build' or 'frame' size. Build had to be assessed subjectively when using these categories for each individual and the 3 W/H^2 ranges taken as 'desirable' for the 'small', 'medium' and 'large' build.

Mean fat content rose with increasing frame category possibly reflecting the fact that each category contained not only people with that 'frame size' but also individuals of other 'frame' sizes who were relatively fat.

As age increased, the mean fat content within each 'frame' category also increased, demonstrating again that age must be taken into account when using W/H^2 as an indicator of 'fatness'. 'Medium frame' 17-19y olds had fat contents of on average 14.7%, while 45-49y olds in the same category averaged 21.5%, perhaps not so 'desirable'. These results intiially suggest that an age correction should be made to the W/H^2 ranges in order to reduce the 'desirable' fat content in the older groups. An objection against this however, is that any correction would be very population dependent since the average percent fat within any age group is population dependent. Even within one population, it would be difficult to calculate a valid correction, because of the wide FFM and percent fat ranges within any small W/H^2 range, demonstrated in Section 2.6.2(c). It should be noted nevertheless, that these wide percent fat ranges within the 3 W/H^2 ranges demonstrated that they themselves do not represent 'frame' categories. They merely represent possible 'desirable' ranges of W/H^2 for individuals

Mean % Fat and SD within 'Desirable' W/H^2 ranges related to 'Frame' Size and within Age Groups

Table 12(a)

Males

Age (yrs)	Small 'Frame' 19.7-21.2	Medium 'Frame' 20.7-22.9	Large 'Frame' 22.1-24.9
16	12.4 ± 2.1	13.4 ± 2.4	14.9 ± 2.8
17-19	13.3 ± 2.5	14.7 ± 2.8	17.0 ± 3.0
20-24	12.6 ± 2.6	14.4 ± 2.8	16.5 ± 3.2
25-29	13.1 ± 2.7	14.3 ± 2.8	16.7 ± 3.3
30-34	16.1 ± 2.4	18.2 ± 2.7	19.9 ± 2.5
35-39	16.7 ± 2.6	17.7 ± 2.7	20.0 ± 2.6
40-44	17.0 ± 2.0	20.3 ± 3.2	22.5 ± 3.4
45-49	19.2 ± 3.7	21.5 ± 3.5	22.7 ± 2.9
> 50	19.8 ± 5.4	20.8 ± 2.7	25.0 ± 3.4

Table 12(b)

Females

Age (yrs)	Small 'Frame' 19.1-20.6	Medium 'Frame' 20.1-22.5	Large 'Frame' 21.4-24.6
17-19	24.2 ± 2.9	26.3 ± 3.1	28.3 ± 2.9
20-24	23.9 ± 3.0	26.1 ± 3.0	28.6 ± 3.2
25-29	22.7 ± 3.8	25.4 ± 4.3	27.8 ± 3.8
30-39*	26.9 ± 1.9	28.9 ± 2.0	29.9 ± 2.4

* Females between 30-39 years were analysed in order to increase the value of n.

of supposedly known 'frame size'.

Females

The female subjects between the ages of 17 and 39y were divided into 4 age groups and within each group they were again divided into 3 female W/H^2 ranges as suggested by the DHSS/MRC group. Fat contents within each group are described in Table 12(b). In a similar manner to that used on male subjects, each females's 'frame' had to be subjectively assessed when using these categories and the 3 W/H^2 ranges taken as 'desirable' for small, medium and large framed individuals.

Mean fat content rose with increasing 'frame' category for the same reasons suggested in the male results.

As age increased, unlike the male sample there was only a small general increase in percent fat. Medium 'framed' 17-19y olds and 30-39y olds had fat contents of 26% and 29% respectively.

If these 'frame' categories are used therefore, their limitations must be known. First of all, they rely on subjective impressions of 'frame' to put people into subjectively assessed 'frame' categories. They have all the drawbacks of the 'Weight for Height Tables' from which they were calculated, and therefore inaccurate assessment of 'frame' could lead to unrealible recommendations on weight, as described in Section 2.6.1.

Secondly, the 3 W/H^2 ranges do not measure 'fatness' since percent fat increased with increasing age while the index remained constant. In all the older age groups of men the mean fat contents were above what would probably be termed as desirable i.e. about 20% fat. It was not possible to recommend accurate age 'corrections', even within this population, because the average percent fat values in each W/H^2 category included individuals from other 'frame' categories who did not fall within their 'desirable' W/H^2 range.

(ii) Obesity Grades

In order to assess the accuracy and value of Garrow's 4 grades of W/H^2 described in section (i) in reflecting percent fat, 5336 and 1086 female subjects were grouped according to both age and W/H^2 as described in Table 13. These values of 'n' are larger than those used in earlier sections of

Table 13(a)

Mean % Fat within W/H^2 'Obesity Grades' and Age Groups

Males

W/H^2	20-24.9		25-29.9		30-39.9	
Age (Yrs)	Mean	SD	Mean	SD	Mean	SD
16	13.7	2.7	19.9	3.4	-	-
17-19	15.3	3.2	21.8	3.1	25.8	2.8
20-24	15.2	3.4	21.2	3.4	26.3	2.4
25-29	15.5	3.5	20.6	3.1	26.0	2.6
30-34	19.1	2.1	23.3	2.7	27.0	2.1
35-39	19.2	2.9	22.9	3.7	26.7	2.0
40-44	21.7	3.7	26.5	3.4	31.0	3.2
45-49	22.1	3.3	27.2	3.3	31.2	2.3
50	23.6	4.1	28.6	3.6	36.0	4.6

Females

Table 13(b)

17-19	27.6	3.1	32.7	2.3	35.8	0.5
20-24	27.6	6.5	33.4	3.1	37.7	2.1
25-29	26.9	4.3	32.9	1.9	36.3	1.9
30-39	29.3	2.4	34.6	2.7	-	-

Only groups with $n \leq 3$ were analysed the analysis because new data became available, but these differences are believed to have little or no influence on the results.

There were no male or female subjects within obesity grade 3. In both sexes mean percent fat increased from Grade 0 to Grade 2, but it also increased with age with the result that the Grade 0 individuals over 40y had fat contents similar to the Grade 1 individuals below 40y. Age therefore must be taken into account if these categories are to be used.

The value of these grades is dependent on one's definition of 'obesity'. About 50% of the male 16y olds and 16% of those between 17 and 29y who were within Grade 1 actually had fat contents below about 19% of their weight. Although 19% might be considered slightly 'overfat' this level would not be considered 'obese' by most UK standards. Because of this problem in definition which is not easily answered, it is not feasible to add an age correction to these grades. A level of fat considered 'obese' in 17-19y olds may not be considered 'obese' in 40-49y olds.

Summary

If W/H^2 is used within 'recommended' ranges as an indicator of 'fatness', then its limitations should be realised.

Some ranges i.e. DHSS/MRC are designed to indicate 'desirable' weights on the assumption that this also represents a 'desirable' fat content. The inclusion of 'frame' categories theoretically improves the accuracy of these recommendations, but has the drawback that it relies on subjective impressions of 'frame'.

Obesity ranges (Garrow 1981) are designed to indicate 'unacceptable' as opposed to 'desirable' fat contents, but take no account of differences in W/H^2 due to 'build'.

Both types of range also have the drawbacks that they are very age and population dependent, and are therefore possibly of most value in comparative studies of groups of similar ages and from similar populations. Across populations or age groups, similar W/H^2 values are likely to represent very different fat contents. The ranges are also of little value for studies on individuals because they cannot take individual variations in bone size or musculature accurately into account.

2.6.3. Skinfold Thickness Measurements

(a) Rationale Behind the Method

A third method often used in both clinical and field studies, is the measurement of skinfold thicknesses at one or at several well defined sites. This method is based on the assumption that a predictable proportion of the total body fat is situated subcutaneously and therefore if subcutaneous fat is measured indirectly from skinfolds, it will provide an estimate of the total body fat content.

The exact proportion of total fat found in the subcutaneous tissues does however vary and appears to depend on many factors, the most important being age, sex and degree of obesity. Other factors may include ethnic origins, fitness and level of activity. One probable reason for the range of results found on this subject is that these factors are difficult to fully standardise and have often not been taken into account. In 1906, Vierondt stated that about 50% of total body fat is situated subcutaneously, while Skerlj et al (1953), who studied 3 groups of females aged (a) 18-30y, (b) 31-45y and (c) 46-67y found that the ratio of subcutaneous to total body fat decreased from 0.26 in group (a) to 0.22 in groups (b) and (c). Young et al (1963) found a similar decrease in the proportion of subcutaneous fat in females but only after the age of about 50y.

Edwards (1950) studied the distribution of subcutaneous fat in 138 females weighing between 90 and 275lbs, initially correcting each weight for height differences. He found a quadratic relationship between the sum of 53 skinfolds and body weight, which suggests that as weight increased, subcutaneous fat increased almost proportionally. Beyond about 200lbs however, fat was deposited internally and therefore the proportion of subcutaneous fat fell slightly. Allen et al (1956) on the other hand, measured 87 Formosan males and females and estimated that the proportion of fat situated subcutaneously rose from 0.25-0.33 in lean individuals, to approximately 0.5 in the obese or 0.65 in the very obese. They did not find any fall in this proportion in the very obese subjects.

When taking sex into consideration, Edwards (1951) found that taking individuals of average weight, females tend to have skinfold thicknesses on average 1.75 times greater than males. Wilmer (1940) found that the skin plus tela subcutanea made up about 17% of the body weight in males (mean weight 57.3kg) and 30% in females (mean weight 50.2kg).

Cadaver analysis carried out by Alexander (1964) suggested a roughly linear relationship between subcutaneous fat measured at 3 sites and internal fat measured at the intrathoracic and intra-abdominal sites. His results however showed considerable variability and he suggested the proportions of subcutaneous fat to be 80% for males and 90% for females. This result is so different from the results of other groups, that it is very likely to be incorrect. Forbes and Amirhakimi (1970) and Durnin and Womersley (1974) both found that males when compared with females had a higher proportion of their fat situated subcutaneously, and therefore for any skinfold value, females would tend to have higher total fat contents than males.

A more extensive review of this subject is given by Womersley (1974).

(b) Selection of the Skinfold Sites

In choosing suitable skinfold sites, several basic factors must be taken intoa account. The fold must be relatively easily picked up and not too firmly attached to the deep fascia. The site must be accurately definable and located easily by different observers, since the difference between 2 sites only a few cms apart can be considerable (Garn, 1954). Where possible sites should be chosen which do not exhibit a lot of variation from nearby sites. In addition, the few sites measured must be representative of total body fat.

Edwards (1950), (1951) studied initially 93 then 53 skinfold sites in order to describe the distribution of subcutaneous fat and the different patterns related to sex and maturity. He found that prior to puberty there was little difference in the pattern between the sexes but that the thickness of the subcutaneous layer did vary from site to site. After puberty differences between the sexes appeared. In males, the proportion of fat on the trunk, posterior and lateral surfaces increased while the limb proportion decreased. The female changes were less marked but a small increase occured together with a slight decrease on the anterior surface and on the arms. The proportion of fat on the legs also increased slightly resulting in females having about 1.25 times as much fat at that site when compared to men, relative to their total body fat. Edwards also found a lot of interindividual variation and a change in the pattern between very thin or obese individuals.

These were very extensive results from 1 study and have been backed up by many other workers (Garn, 1954; Reynolds, 1951; Siervogel et al, 1982) but they were purely descriptive and Edwards did not attempt to relate the skinfolds to body fat content.

Further studies increased the interest in subcutaneous fat and its distribution and Reynolds (1951) measured the thickness using radiographic techniques at 6 sites; calf, thigh (trochanter), waist, chest, deltoid and forearm, in children involved in the Fels Longitudinal Study. He found that the correlations between pairs of sites increased in both sexes between 7.5-11.5y of age. While it then continued to increase in girls up to about 15.5y, it changed little in boys in the same age range. Trochanteric fat thickness was most highly related to the other sites in boys and was therefore the best single site for indicating fat content, while in females the 'best' sites were the deltoid and forearm.

These measurements were not validated against more accurate laboratory measures of fat content, but this did not nulify the value of the work, since in order to choose the most accurate sites for reflecting fat content and thus reduce the number from Edward's 53 sites, fat patterning had to be studied, as did the correlations between measurements at different sites. The best sites, ideally, would be those which correlated highly with fat thickness at other sites and were representative of the overall fat distribution.

Information on fat patterning in adults was still limited at this stage, and therefore Garn (1954) studied the patterning and intercorrelations in 81 adult males between 20-69y of age, again using radiographic techniques since it allowed more exact localisation of the sites. The x-rays were taken at 6 sites, and allowed fat thickness measurements at 9 sites to be recorded: deltoid insertion, lateral and medial arm at the point of maximum muscle diameter, iliac, trochanteric, posterior and anterior leg, medial and lateral leg.

Garn found that the trochanteric site was most highly correlated with the other sites and with weight. He also notes however that while medial leg fat also correlated highly with the other sites, posterior leg fat, only a few cm removed, showed the poorest inter-site correlation and therefore it is most important that sites be accurately defined and relatively easily located.

Mueller and Stallones (1981) suggested that in order to discriminate between the extremity-trunk fat patterning, a trunk and leg skinfold should be measured and compared, but leg skinfolds have not generally been popular because of their general low correlations with other measures of fatness.

Overall, therefore, fat patterning and distribution studies have provided a general indication of which skinfold sites would be the most useful for assessing 'fatness'.

The Introduction described various studies where skinfold measurements were actually related to body fat mass, FFM or body density, and it is from these studies, where correlations and regressions were examined, that the 'best' skinfolds have finally emerged. By compiling the results from all this research the International Biological Program (Weiner and Lourie, 1969) recommended that the biceps, triceps and subscapular skinfold sites be measured, together with any other 'preferred' sites.

(c) Converting Skinfold Measurements into Body Fat Values

The equations of Durnin and Womersley (1974) have been used in this study to predict body density from the sum of the biceps, triceps, subscapular and supra-iliac skinfolds. Body density was then converted into body fat content (percent fat), using the equation of Siri (1956). The methodology of taking the measurements is explained in Section 2.8.1., and the relevant equations are shown below. The 16y olds in this study were included with the 17-19y olds, when calculating percent fat.

Durnin & Womersley: Equations

AGE GROUP	MALE	FEMALE
17-19	$D = 1.162 - 0.063 \log (\Sigma sk)$	$D = 1.1549 - 0.0678 \log (\Sigma sk)$
20-29	$D = 1.1631 - 0.0632 \log (\Sigma sk)$	$D = 1.1599 - 0.0717 \log (\Sigma sk)$
30-39	$D = 1.1422 - 0.0544 \log (\Sigma sk)$	$D = 1.1423 - 0.0632 \log (\Sigma sk)$
40-49	$D = 1.1620 - 0.070 \log (\Sigma sk)$	$D = 1.1333 - 0.0612 \log (\Sigma sk)$
50-68	$D = 1.1715 - 0.0779 \log (\Sigma sk)$	$D = 1.1339 - 0.0645 \log (\Sigma sk)$

Key: Σ sk = the sum of the biceps, triceps, subscapular and suprailiac skinfolds

D = Body Density

Siri (1956):

$$\% \text{ Fat} = \left(\frac{4.95}{\text{Density}} - 4.50\right) \times 100$$

A major problem with all prediction equations is that they tend to be population specific i.e. provide very good predictions for the population from which they were made, but not necesarily any other populations. Haisman (1970) attempted to assess the value of 8 skinfold-to-body fat equations, by relating their predictions to results obtained by the densitometric method. His subjects were 55 young males of average age 22.6 $\pm$ 2.2 years, and among his equations were included one calculated by Durnin and Rahaman (1967), for young and adolescent males.

$$\text{Body Density} = 1.1610 - 0.0632 \log(\Sigma sk)$$

Haisman found that of the 8 equations, this one showed the best agreement between body density calculated by densitometry and a prediction equation on his sample of young men. He also concluded, in agreement with Durnin and Rahaman, that formulae including variables such as height, weight or age together with skinfolds added nothing to their predictive ability, in his sample.

Later studies however i.e. Durnin and Womersley (1974) found that age was an important factor and this point was probably missed by Haisman because of the small age range within his sample.

The error involved in estimating density and thus percent fat from these skinfold measurements can be estimated from the values for the Standard Errors of the estimates (SE_E) of the predicting equations. In the males, these ranged from 0.0073 (kg/m^3) in the 17-19y olds to 0.0092 (kg/m^3) in the 50-68y olds, and when converted into percent fat using Siri's equation, represented errors of between about $\pm$ 3% and $\pm$ 4% fat.

In the female sample, the SE_E ranged from 0.008kg/m^3 in the 50-68y olds to 0.0125 in the 30-39y olds representing values on average about 4% and 6% fat respectively.

For most practical purposes it was considered that these errors in the male sample were acceptable as for most individuals they represented only a few kg in weight, and were unlikely to cause gross misclassification of individuals into obese or non-obese categories.

The errors within the female sample were larger that within the male sample and because of the lower mean weights of the females they represented larger errors in terms of kg. It was therefore concluded that care should be taken in the interpretation of the female results.

It should also be noted that Durnin and Womersley (1974) produced prediction equations for each of the age groups 17-19y, 20-29y, 30-30y, 40-49y and 50y. After about the age of 20y, increasing age is related to an increase in fat content but also to a redistribution of body fat. As a result, one value for the sum of 4 skinfolds indicates increasing percent fat values as age increases, and from one age equation to the next there is therefore a slight jump in predicted fat content. Between the male 17-19y and 20-29y groups however, there is actually a slight fall. As the age groups are listed above, these jumps are approximately -0.3%, 3%, 2% and 1.5% in males and 0.4%, 2% 2.5% and 2% in females.

Although these changes do reflect actual increases in fat content with age, they almost certainly occur gradually so that no emphasis should be put on sudden changes in percent fat or FFM which occur between decades. Since each equation represents an average within its age range, within that range the percent fat of the younger half is probably slightly overestimated and of the older half, slightly underestimated.

These factors should be kept in mind when graphs of either FFM or percent fat are plotted against age.

Although the methodology of measuring skinfolds is relatively simple, it was noted in chapter 1 that the observer does require training in the techniques of accurately locating the site, picking up the skinfold, applying the calipers at the correct point etc. The calipers themselves must be treated carefully and have their calibration regularly checked. For these reasons, there is a need to produce a more simple method for estimating fat content which requires only basic training and equipment.

2.7. EQUIPMENT

Throughout the survey, the following equipment was used:-

(a) Weighing machines: Salter Model 109 (floor model) and Brash Model 424 weighing machine. The Salter scales are spring scales with a carrying handle and transit lock and have a capacity of 150kg x 0.5kg. The Brash scales are portable pillar scales with moveable weights, and a capacity of 160kg x 0.05kg. After every field trip, the scales used were checked with standard weights and recalibrated if necessary. Overall, the Salter scales were used more often, since they proved more portable, and the additional accuracy of the Brash scales was not required.

(b) Skinfold calipers: Holtain/Tanner - Whitehouse skinfold calipers were used. The pressure between the anvils of 10gms/Sq.mm was checked using weights, before each field trip. The weight calculated by multiplying the measured surface area in mm, of the caliper jaw by 10, was hung by a thread to the caliper jaw. If the caliper pressure was correct, this weight held the jaws still at any opening distance. Errors of up to $\pm$ 2gm/mm^2 were considered tolerable.

The dial calibration was also checked using a set of standard, measured lengths and had to be accurate to $\pm$ 0.1mm. If the calipers required repair they were sent back to Holtain Ltd. Range 0-48mm x 0.2mm.

(c) Anthropometer: the Harpenden anthropometer was used for measuring biacromial and bi-iliac diameters. The straight branches were always used. Range 50-570mm x 1mm.

(d) The Holtain Bicondylar Vernier was used to measure wrist and knee diameter. Range 0-140mm x 1mm.

(e) Measuring tape: a metal flexible tape, 3M x 1mm was used to measure limb circumferences.

(f) Stadiometer: a portable stadiometer was built by the departmental workshops. The height bar separated into two pieces and the base plate and head bar were also removable. Range 0-2M x 1mm.

2.8. ANTHROPOMETRY

2.8.1. Anthropometric Measurements

The anthropometric measurements taken are listed below. The four skinfolds were taken as described by Durnin & Rahaman (1967). Circumferences, bone diameters, height and weight were measured using the standard techniques described by Weiner and Lourie (1969) in the I.B.P. Handbook.

Measurements taken

a. Stature
b. Weight
c. Skinfolds: Biceps
Triceps
Supra-iliac
Sub-scapular

d. Circumferences: Calf
Thigh
Buttocks
Upper Arm

e. Bone Diameters: Ulnar
Tibial
Biacromial
Bi-iliac

Stature

Each subject stood on the horizontal platform of the stadiometer with his heels together, stretching upwards to his fullest extent. His back was as straight as possible against the vertical bar of the stadiometer and his Frankfort plane was checked to be horizontal. He was asked to 'take a deep breath' in order to make him stretch up, and the head-bar was then brought down on to his head. The subject's heels were always watched to make sure that he did not raise them. Readings were taken to the nearest mm.

BODY WEIGHT

Weighing was carried out with the subject clothed only in underwear or light sportswear. (For any other article of clothing worn, the weight was corrected by weighing the article and subtracting this from the inital weight obtained.) Readings were taken to the nearest 0.1kg.

SKINFOLDS

The skinfolds were picked up between the thumb and forefinger and the caliper jaws applied at the skinfold site, approximately 1cm below the forefinger and thumb. The measurement was read two seconds after the full pressure of the caliper jaws was applied to the skinfold. Each reading was to the nearest 0.2mm.

Biceps: The skinfold was picked up on the front of the relaxed arm at the mid-point of the belly of the muscle. (This site was marked initially until the observers felt sufficiently competent at locating the exact site by eye alone.)

<u>Triceps</u>: The skinfold was taken at the back of the relaxed arm, at the mid-point between the acromion process and the olecranon process. The measurement was taken at this mid-point, and directly in line with the two processes. (This site was marked on every subject).

<u>Subscapular</u>: The skinfold was picked up under the angle of the scapula, just below the tip of the inferior angle of the scapula, at an angle of about 45° to vertical, and with the fingers touching the bone.

<u>Supra-iliac</u>: This measurement was taken just above the iliac crest, on the mid-auxillary line. (This site was initially marked, again, until the observers felt competent at locating the exact site.)

Each of these measurements was taken in triplicate and the mean, to the nearest mm, was recorded.

<u>CIRCUMFERENCES</u>

<u>Upper Arm</u>: The subject's arm hung relaxed, just away from his side and the horizontal circumference was taken midway between the inferior border of the acromion process and the tip of the olecranon process. This measurement overlapped the triceps skinfold site.

<u>Calf</u>: The subject sat on a table with his legs hanging freely and the back of his knee touching the table. By moving the tape up and down his leg the maximum horizontal circumference was located and measured.

<u>Thigh</u>: The subject stood with his feet slightly apart and weight evenly distributed on both feet. The measurement was taken with the tape placed around the thigh horizontally with its top edge just under the gluteal fold.

<u>Buttocks</u>: The maximum horizontal circumference was measured.

<u>BONE DIAMETERS</u>

<u>Wrist Breadth</u>: The breadth was taken across the styloid processes (oblique to the long axis of the arm), with pressure applied to compress the

tissues.

Bicondylar Femur (Knee): The subject sat on a table with his knees bent to a right angle, and the width across the outermost parts of the lower end of the femur was measured. Pressure was exerted to compress the tissues.

Biacromial Diameter: To give maximum shoulder width the subject stood with his shoulders relaxed. Standing behind the subject, the measurer felt for the outside edges of the acromion processes which could be felt as ridges just above the shoulder joints. He then placed the two arms of the anthropometer along the lateral borders of the acromion processes and asked the subject to relax his shoulders as much as possible. The measurement was then taken, with pressure applied to compress the overlying tissues.

Bi-iliac Diameter: The subject stood with heels together and the anthropometer arms were brought into contact with the iliac crests at the site which gave the maximum diameter. Strong pressure was applied to the anthropometer blades to push aside any fat covering the bone. This measurement was always taken with the measurer standing behind the subject.

Reasons behind choosing these Specific Measurement Sites

The list of measurements taken in this project are taken from a Basic List which is described by Weiner and Lourie (1969). This 'basic list' contains 21 measurements that were recommended for studies on growth and physique. It was felt, however, that considering the practical problems involved in a study of several thousand individuals it would be impracticable and unnecessary to carry out all of these 21 measurements. The combination of measurements taken in this survey are sufficient to assess muscle mass, 'frame size' and body fat.

2.8.2. Reproducibility of Repeat Measurements taken by One Observer

The initial reproducibility study involved 1 observer, 8 male and 8 female subjects. It examined:

1. The reproducibility of various anthropometric measurements taken on 3 seperate days, on each subject.

2. The difference between measurements taken on the left and right-hand sides of each subject.

(a) Skinfold Measurements

The biceps, triceps, subscapular and supra-iliac skinfolds were measured on all 16 subjects, on both sides of the body. On each of 2 other days within the same week, these 8 skinfolds were repeated. The previous results were unknown to the observer.

For each subject and for each side of the body, the mean measurement and S.D. were calculated at each site. In these circumstances the S.D. indicated the reproducibility of the repeat measurements, and expressed as (SD/Mean) x 100 the sites could be compared. This figure was calculated for each individual, at each site.

These values for the means, SDs and (SD/Mean)s for each individual were then combined, males and females separately, and the group averages calculated. These results are shown in Table 14(b) and (c).

(i) Reproducibility at Single Sites

Examining the values for the average (SD/M) as a percentage in Table 14; showed that the sites of best reproducibility were the subscapular in males, and the triceps in females, with minimum values of 2.3% and 4.7% respectively. The sites of worst reproducibility were the supra-iliac in males and biceps in females. The mean SD, however, was less than 1.5mm at all sites and the mean (SD/M) x 100 never exceeded 10%.

When the sum of the 4 skinfolds was calculated, the maximum mean SD was 2.1mm or approximately 4% of the mean. On calculating percent fat, using the equations of Womersley and Durnin (1974), these variations represented SDs of less than 1% body fat. Once the sum of skinfolds was calculated, the value for mean (SD/M) x 100 was found to be less than that at most individual sites because many small variations at sites cancelled out when they were summed.

Tables 14(b) and (c) also show that the reproducibility of 3 repeat

Table 14(a)

Description of Male and Female Subjects in Initial Reproducibility Study

	n	Mean Age (yrs)		Mean Height (m)		Mean Weight (kg)		Mean % Fat	
Males	8	21.1	(1.5)	1.78	(0.06)	72.1	(6.8)	15%	(2.8)
Females	8	24.0	(3.6)	1.64	(0.06)	61.0	(7.1)	27%	(3.5)

No in brackets = SD

Table 14(b)

Mean Values for Skinfold Measurements, on the Left and Right Hand Side of the Body, plus mean SD after repeat Measurements on each subject

	Biceps (mm)		Triceps (mm)		Subscapular (mm)		Suprailiac (mm)		Total (mm)	
Males	L Side	R Side	L Side	R Side	L Side	R Side	L Side	R Side	L Side	R Side
Mean Measurement	4.6	4.2	10.2	10.6	9.4	9.5	12.3	13.9	36.5	38.2
Mean SD	0.3	0.3	0.5	0.4	0.2	0.2	1.0	1.4	1.6	1.4
Mean $(\frac{SD}{M})$ z 100	7.5	7.6	5.0	3.8	2.3	2.5	8.3	9.4	4.2	3.4

Table 14(c)

	Biceps (mm)		Triceps (mm)		Subscapular (mm)		Suprailiac (mm)		Total (mm)	
Females	L Side	R Side	L Side	R Side	L Side	R Side	L Side	R Side	L Side	R Side
Mean Measurement	7.0	5.9	18.3	19.5	12.2	12.1	14.4	14.3	51.8	51.9
Mean SD	0.7	0.4	0.9	1.0	0.7	0.8	0.9	1.1	1.4	2.1
Mean $(\frac{SD}{M})$ x 100	9.5	6.4	4.8	4.7	5.3	6.6	6.0	7.8	2.8	3.7

measurements was equally as good on the right and left sides of the body.

These results are similar to those of Womersley and Durnin (1973) who found that with individual observers the best reproducibility of measurement was in the 'Sum of 4 Skinfolds'. At individual sites the most reproducible were the subscapular in males and the triceps and supra-iliac sites in females.

Each skinfold was measured on 3 occasions, on 2 sides of the body, producing 6 values for each subject. The male and female results were then summed separately, to form six sets of 8 values for each site, 3 from each side of the body. These sets were compared, using Analysis of Variance (AOV) and it was found that there was no significant difference between mean values at any one site taken on the same side of the body.

(ii) Differences Between Measurements taken on the Right and Left Sides of the Body

Comparisons were made at each site between the 3 sets of measurements described above on each side of the body, analysing male and female subjects separately. 2-Factor AOV and student's t-tests were used to compare the means of each set, and the assumption was made that the SDs of the sets at each site were approximately constant. The results are shown in Table 15.

In both males and females, there were no significant differences between the means on either side of the body, at the triceps and subscapular sites. With females, there were also no significant differences at the supra-iliac site or in the total of the 4 skinfolds, although they did show significant differences at the biceps site.

Although significant, differences between the sides of the body were usually small, and at an individual level the maximum difference in 'Total Skinfolds' on each subject are shown in Table 16. It can be seen that there was a tendency for subjects with the highest fat contents to show the largest difference in Total Skinfolds (mm). This aspect is studied in the next section.

In conclusion, therefore, it was found that:

Comparisons between sets of measurements, taken on the Right and Left hand sides of the body – only significant differences are mentioned below

Subjects	Biceps: Measurement Sets	Biceps: Signif Level	Triceps: Signif Level	Subscapular: Signif Level	Suprailiac: Measurement Sets	Suprailiac: Signif Level	Total Skinfolds	Total Skinfolds: Signif Level
Males	$M2_L$-$M5_R$	*	NS Diff between $M1_L$ to $M6_R$	NS Diff between $M1_L$-$M6_R$	$M1_L$-$M4_R$	**	$M1_L$-$M4_R$	*
					$M1_L$-$M5_R$	**	$M1_L$-$M5_R$	**
					$M1_L$-$M6_R$	*	$M1_L$-$M5_R$	*
					$M2_L$-$M5_R$	*	$M3_L$-$M4_R$	*
					$M3_L$-$M4_R$	*	$M3_L$-$M5_R$	*
					$M3_L$-$M5_R$	**	$M3_L$-$M5_R$	*
Females	$M1_L$-$M4_R$	*	NS Diff between $M1_L$ to $M6_R$	NS Diff between $M1_L$ to $M6_R$	NS Diff between $M1_L$ to $M6_R$		NS Diff between $M1_L$ to $M6_R$	
	$M2_L$-$M5_R$	**						
	$M2_L$-$M4_R$	**						
	$M2_L$-$M6_R$	**						

Analysis was carried out using 2-factor AOV and Students t-tests

$M1_L$, $M2_L$, $M3_L$ – sets of measurements from the left hand side (n=8)

$M4_R$, $M5_R$, M6R – sets of measurements from the right hand side (n=8)

Key:
- * – $p < 0.05$
- ** – $p < 0.01$
- NS – No significant difference between results from the left and right hand sides

Table 16

Maximum Difference between the Sum of 4 Skinfolds calculated on three occasions on the Right Side and three on the Left Side of the Body

Males				Females			
Subject	mm	% Fat	Mean Fat Content*	Subject	mm	% Fat	Mean Fat Content*
1	2.0	1.0	13%	1	13	3.0	28%
2	7.0	1.5	19%	2	2	1.0	24%
3	6.0	1.0	13%	3	7	1.0	31%
4	8.0	2.0	18%	4	2	1.0	19%
5	1.5	0.5	11%	5	5	1.0	30%
6	7.0	1.5	18%	6	3	1.0	25%
7	4.0	1.0	14%	7	3	1.0	26%
8	2.0	1.0	14%	8	10	2.0	31%

*Calculated using the Equations of Durnin & Womersley (1974)

a. Repeat measurements taken by 1 observer on 1 side of the body, on 3 occasions, caused a mean variation in calculated fat content, of about 1% fat in males and females. The maximum variation in any individual was about 2% fat for both sexes.

b. The most reproducible sites were the subscapular and triceps sites, in males and females respectively.

c. The least reproducible sites were the supra-iliac and biceps sites, in males and females respectively.

d. The skinfold measurements were equally reproducible on the right and left sides of the body.

e. The most significant differences between sides were found at the supra-iliac and biceps sites in males and females respectively. These were also the least reproducible sites, as mentioned in conclusion (c).

f. When the sum of the 4 skinfolds were compared after measurement taken on both right and left sides, there were no significant differences between the means in females, but the differences were significant at the 99% level in males.

g. The largest differences in calculated fat content between the 2 sides were 2% and 3% in males and females respectively. These differences could be due to experimental error in taking repeat measurements, and possibly also to slight differences in actual fat distribution between the right and left-hand sides of the body in some subjects.

It was concluded that because these error variations were small, the skinfolds could be measured on either side of the body, but care ought to be taken most especially at the supra-iliac site in males and biceps site in females.

(b) Bone Diameters

Tables 17(a) and (b) give values for the mean, mean SD and mean (SD/M) x

Mean Values for Bone Diameters and Height taken three times each

on the Right and Left Hand Sides of the Body: Eight Male and eight Female Subjects

The Mean SD for the three Repeat Measurements and Mean $(\frac{SD}{M}) \times 100$ are also shown

Table 17(a)

Males	Height (cm)	Ulna (cm)		Tibia (cm)		Biacromial D	Bi-iliac D (cm)
	—	L Side	R Side	L Side	R Side	—	—
n	8	8	8	8	8	8	8
Mean Measurement	178.00	5.53	5.56	9.60	9.60	39.4	26.7
Mean SD	0.38	0.10	0.13	0.09	0.09	0.3	0.1
Mean $(\frac{SD}{M}) \times 100$	0.20%	1.80%	2.30%	1.0%	1.0%	0.7%	0.40%

Table 17(b)

Females	Height (cm)	Ulna (cm)		Tibia (cm)		Biacromial D	Bi-iliac D (cm)
	—	L Side	R Side	L Side	R Side	—	—
n	8	8	8	8	8	5	5
Mean Measurement	163.90	4.7	4.7	8.80	8.90	36.0	26.0
Mean SD	0.34	0.1	0.1	0.06	0.04	0.3	0.5
Mean $(\frac{SD}{M}) \times 100$	0.2%	1.7%	2.0%	0.60%	0.50%	0.7%	1.8%

100, calculated from 3 repeat measurements on the left and right hand sides of the body where possible, as described in section (a) on skinfolds.

The most reproducible measurements, for both males and females, was standing height, as shown by the low value of (SD/M)%, of 0.2%.

The least reproducible measurements were ulnar diameter, with a maximum mean (SD/M)% of about 2.3% and 2.0% in males and females respectively, and also bi-iliac diameter in females. The maximum mean SDs however were only 0.13cm at the ulnar site and 0.5cm at the bi-iliac site and therefore, although significant, the difference was relatively unimportant. There was no significant difference in reproducibility between ulnar and tibial diameters taken on the left and right-hand sides of the body.

In practical terms, overall reproducibility of the 3 measurements was high, as at all the sites the largest SD for any individual was less than 4% of the mean. Even at the ulnar site, the largest difference between 2 measurements on one subject was only 3mm.

The relatively poor reproducibility of the bi-iliac diameter in females, where the maximum SD in 1 subject was approximately 1cm, may be due to the fact that in general females have more adipose tissue in this area. This makes it more difficult to locate the exact measurement site, and to include a minimum of adipose tissue in the measurement.

Differences between measurements taken on the left and right-hand sides of the body never exceeded 0.3cm, and it was concluded that the measurements could therefore be taken from either side.

(c) Circumferences

Tables 17(c) and (d) give values for the mean SD and mean (SD/M)%, for each circumference, calculated as described in section (a) on skinfolds.

There appeared to be no significant differences between males and females in the reproducibility of these measurements. The most reproducible were the calf and buttocks circumference, with (SD/M)%s of approximately 0.6% in both sexes at both sites. The least reproducible was the upper arm

Mean Values for Circumferences, taken three times

on the Right and Left Hand Sides of the Body: Eight Male and eight Female subjects

The Mean SD for the three Repeat Measurements and Mean $(\frac{SD}{M}) \times 100$ are also shown

Circumferences:

Table 17(c)

Males	Calf (cm) L Side	Calf (cm) R Side	Thigh (cm) L Side	Thigh (cm) R Side	Buttocks (cm)	Upper Arm (cm) L Side	Upper Arm (cm) R Side
n	8	8	3	3	3	8	8
Mean Measurement	37.80	37.90	52.20	52.60	94.20	26.90	29.10
Mean SD	0.25	0.22	0.51	0.59	0.68	0.35	0.46
Mean $(\frac{SD}{M}) \times 100$	0.60%	0.60%	1.00	1.10%	0.70%	1.20%	1.60%

Table 17(d)

Females	Calf (cm) L Side	Calf (cm) R Side	Thigh (cm) L Side	Thigh (cm) R Side	Buttocks (cm)	Upper Arm (cm) L Side	Upper Arm (cm) R Side
n	8	8	8	8	8	8	8
Mean Measurement	34.80	34.80	54.10	54.20	92.90	26.10	26.50
Mean SD	0.19	0.21	0.70	0.70	0.55	0.34	0.27
Mean $(\frac{SD}{M}) \times 100$	0.50%	0.60%	1.30%	1.20%	0.60%	1.30%	1.00%

circumference, with a mean (SD/M) of approximately 1.3%, but this only represented a mean SD of approximately 0.35cm.

There were no differences in the reproducibility of the measurements, between the right and left-hand sides of the body.

The overall reproducibility of the 3 repeat measurements was high, as the maximum value for (SD/M)% for any subject was 3%, found at the upper arm site in both sexes. At the calf and buttocks sites it never exceeded 1.5%.

At an individual level the maximum differences between calf measurements taken on the left and right-hand sides were 1.6cm in the males and 1.3cm in the females. Differences in upper arm circumference reached maximums of 2.7cm and 2.1cm in males and females respectively. When AOV was used to look at these differences between sides however, the only significant differences at the 95% level were found at the calf, in females. Because of the small magnitude of these differences they were nevertheless considered to be relatively unimportant.

These differences were well over the maximum observer error found after 3 repeat measurements at one site, and were therefore probably largely due to actual differences in muscle bulk between the 2 sides. Differences in fat distribution may also account for some of the difference. When examined however, subjects involved in sport such as hillwalking or tennis, were often found to have one limb circumference larger than the other, without necessarily having any difference in the skinfold measurements on the 2 sides.

In this study, it was not possible to calculate how significantly the limb circumferences varied between the left and right-hand side of the body in sportsmen because of the relatively low numbers of serious sportsmen and the lack of time available in the field work.

It was decided overall, that despite the differences in limb circumferences between the 2 sides of the body which were greater than the expected observer error after repeat measurements, only 1 side, the right side, would be measured in this survey. This was due to the fact that the differences were generally small, and if an average was taken, the change to either measurement was only of the same order of magnitude as observer error.

In conclusion, it should be noted that particular care should also be taken when measuring at those skinfold, girth and bone diameter sites which have been demonstrated to show poor reproducibility. In addition the variations in calf, thigh and upper arm circumferences, possibly related to sporting activity, should be kept in mind in any further analysis.

2.8.3. Reproducibility of the Anthropometric Measurements Between Observers

Throughout the survey, the 2 observers checked each others' measurements by taking duplicate measurements. Initially every 10th subject was duplicated, but as the survey progressed and the precision became more constant this was reduced to about every 50th. Depending on how much time was available, either all the measurements minus height and weight, or only skinfolds were duplicated. Tables 18 and 19 show the results after analysis of these duplications from the male and female subjects.

Columns 3 and 5 on each table show the mean measurement values at each site, for observers 1 and 2 or 1 and 3. For each individual, the difference and modulus of the difference between the 2 measurements at each site were calculated. From this, the mean difference and mean modulus of the difference were calculated for the entire sample, as shown in columns 7 and 11. The Standard Error and Matched pairs t-tests on the differences were also calculated.

If the difference between the measurements of 2 observers was not consistently in any one direction then the mean difference ($\overline{\text{Diff}}$) would approach zero and the (+)ve and (-)ve differences cancelled out. The modulus however, i.e. $|\overline{\text{Diff}}|$ shows the magnitude of the difference, irrespective of the sign, and is always greater then zero, unless both observers have identical measurements.

(a) Skinfold Measurements

Tables 18(a) and (b) show the results from 2 male and 2 female reproducibility analyses. In the male sample, the mean difference, $\overline{\text{Diffs}}$,

Table 18(a)

Reproducibility Results (a) October-December 1980 (b) February 1981

Skinfolds - MALES

Measurement Site	N	Mean (1) Value	SD	Mean (2) Value	SD	$\overline{Diff}$	SD	$SE_{\overline{D}}$	t	$\lvert\overline{Diff}\rvert$	SD	$SE_{\overline{D}}$	t
(a) Biceps (mm)	74	4.8	1.6	4.7	1.6	+0.12	0.48	0.05	2.16 *	0.35	0.34	0.04	8.6 ***
Triceps (mm)	75	11.4	4.2	11.4	4.4	-0.04	0.60	0.07	0.70 NS	0.50	0.37	0.04	10.6 ***
Subscapular (mm)	75	13.0	5.8	12.8	5.5	+0.23	1.30	0.15	1.56 NS	0.63	0.11	0.13	4.9 ***
Suprailiac (mm)	75	17.3	7.2	17.0	7.2	+0.3	1.02	0.12	2.57 *	0.80	0.70	0.08	10.7 ***
Total Skinfolds (mm)	74	46.3	16.5	45.9	16.7	+0.4	2.93	0.34	1.15 NS	1.50	2.54	0.3	5.1 ***
		(1)		(3)									
(b) Biceps (mm)	52	4.5	1.4	4.6	1.4	-0.10	0.32	0.04	2.32 *	0.27	0.20	0.03	10.0 ***
Triceps (mm)	52	10.0	3.1	9.9	3.3	+0.07	0.64	0.09	0.75 NS	0.44	0.47	0.06	6.8 ***
Subscapular (mm)	52	11.4	3.3	11.4	3.2	0.00	0.60	0.08	0.05 NS	0.43	0.42	0.06	7.5 ***
Suprailiac (mm)	52	16.4	6.7	16.4	6.5	-0.05	1.20	0.17	0.31 NS	0.90	0.78	0.11	8.2 ***
Total Skinfolds (mm)	52	42.4	13.2	42.6	13.3	-0.19	1.67	0.23	0.8 NS	1.27	1.08	0.15	8.4 ***

Observer (1) - Miss McKay
Observer (2) - Miss Grant
Observer (3) - Miss Webster

Key: $p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

Table 18(b)

Reproducability Results (a) November 1979 (b) February 1981

Skinfolds - FEMALES

Measurement Site	n	Mean (1) Value	SD	Mean (2) Value	SD	$\overline{\text{Diff}}$	SD	$SE_{\overline{D}}$	t	$\overline{\lvert\text{Diff}\rvert}$	SD	$SE_{\overline{D}}$	t
(a) Biceps (mm)	40	6.8	2.9	7.6	3.2	-0.87	1.40	0.22	** 3.99	1.2	1.10	0.17	*** 7.06
Triceps (mm)	40	18.6	4.9	18.7	4.9	-0.15	1.60	0.25	NS 0.61	1.2	1.10	0.17	*** 7.06
Subscapular (mm)	40	10.9	3.7	12.0	4.8	-1.06	1.06	0.17	*** 5.98	1.1	0.90	0.14	*** 7.86
Suprailiac (mm)	40	13.0	4.4	13.2	6.1	-0.04	2.30	0.36	NS 0.02	1.4	1.10	0.17	*** 8.23
Total Skinfolds (mm)	40	49.3	14.4	51.6	17.3	-1.95	3.70	0.58	** 3.34	2.8	3.00	0.47	*** 5.90
(b) Biceps (mm)	94	(1) 7.2	2.6	(3) 7.5	2.8	-0.30	0.78	0.08	*** 3.71	0.45	0.71	0.07	*** 6.17
Triceps (mm)	94	20.2	5.9	20.3	5.9	-0.09	0.99	0.10	NS 0.93	0.69	0.72	0.74	*** 9.39
Subscapular (mm)	94	13.8	5.4	13.6	4.9	0.17	1.81	0.18	NS 0.95	0.85	1.59	0.16	*** 5.20
Suprailiac (mm)	94	16.4	5.8	17.2	6.5	-0.78	1.82	0.18	*** 4.20	1.19	1.57	0.16	*** 7.35
Total Skinfolds (mm)	94	57.7	17.5	58.7	17.9	-0.95	2.87	0.29	** 3.20	1.81	2.41	0.25	*** 7.30

Observer (1) = Miss McKay
(2) = Miss Grant
(3) = Miss Webster

Key: $p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***
NS : Not Significant

was less than 0.5mm at all sites, although at the 95% level this was significant at the biceps site in both analyses and at the supra-iliac site in the first analysis. When the four skinfolds were summed however, $\overline{\text{Diff}}$ was not significant as many of the small differences at individual sites were cancelled out.

In the female sample, the Diffs were less than or equal to approximately 1mm at all sites and were significant at the 99% or 99.9% level at the biceps site in both analyses and at the subscapular and supra-iliac sites in the 1st and 2nd analysis respectively. Observer (1) had produced significantly smaller readings than Observers (2) and (3). When the Σ 4 skinfolds was calculated in each analysis the mean differences were 1.95mm and 0.95mm. Although these results were significant at the 99% level they were small and therefore had little effect on the calculated fat content.

In both sexes, the modulus of the mean differences, $|\overline{\text{Diff}}|$, were significant at the 99.9% level at each site, and when the Σ 4 skinfolds were summed. The magnitude of these differences was small however, being less than 1.0mm and 1.5mm at individual sites and less than 1.5mm and 3.0mm when the sites were summed in males and females respectively.

The supra-iliac site in both sexes exhibited the largest $|\overline{\text{Diff}}|$s of any site in terms of mm, but as a percent of the mean measurement value, worst reproducibility occurred at the supra-iliac and biceps sites. The maximum mean $|\overline{\text{Diff}}|$s at the biceps site were 16% and 7% of the mean in males and females respectively. At the supra-iliac site, these maxiumums were 11% and 5.5% in the 2 sexes.

The smallest errors were at the triceps site in the females with values of approximately 6% and 3.5% of the mean in the 2 studies. In males the smallest errors were 4.4% at the triceps in the 1st study and 3.8% at the subscapular site in the 2nd study.

These results are in general agreement with the findings when only 1 observer duplicated the results i.e. Section 2.8.2. Again the most reproducible sites in terms of the error as a percent of the mean, were the triceps and subscapular while the least reproducible were the biceps and supra-iliac. In both sexes, there was also a slight improvement in the reproducibility at single sites, between the 1st and 2nd studies.

The $|\overline{Diff}|$s in the total skinfolds values were approximately 3% of the mean in the 2 male studies and the 2nd female study but approached 6% of the mean in the 1st female study. This larger value was again probably a reflection of the inexperience of Observer 2 at that point in time. It should be noted however that all these values were fairly low. When fat content was calculated as a percent of body weight, these differences in 95% of the subjects, involved errors of less than ± 2% fat in females. Many of the differences at individual sites had cancelled out and these final errors were similar to the maximum error of about 2% found by 1 observer carrying out duplicate measurements.

Tables 19(a) and (b) summarise the differences found between the sums of the 4 skinfolds as measured by the 3 observers throughout the survey. In the males, the greatest range of differences was in study no. 3 where 95% of the sample exhibited differences between (-5.4 to 6.2)mm in the 'Total Skinfolds' value as calculated by the 2 observers. The many small differences however reduced the mean $|\overline{Diff}|$ to only 1.5mm. These large differences however, still only produced differences in calculated fat content between the observers of less than 2% of total body weight in 95% of the subjects.

In the female studies the differences in 'Total Skinfolds' ranged from (-20 to 6.7)mm, and the resulting maximum difference in fat content was 3.5% of body weight.

Since these differences were not consistently in one direction, in the male study and 2nd and 3rd female studies, as demonstrated by the mean Diff being about 1mm or less, i.e. neither observer consistently produced higher results than the other, it was concluded that their measurement techniques were similar and skinfold measurement results could be reproduced between observers.

(b) Circumferences and Diameters

Tables 20(a) and (b) demonstrate the reproducibility of the circumference and diameter measurements. In both sexes, the diameters showed mean differences of $<$0.2cm at all sites, demonstrating that neither observer

Mean Value of "Total Skinfold" as calculated by 2 Observers, measuring the Same Subjects

Mean Difference, modulus Mean Difference and Matched - Pairs t-tests are also included: MALES

Table 19(a)

Study Number	n	Observer 1 Mean	Observer 1 SD	Observer 2/3 Mean	Observer 2/3 SD	Mean Diff	SD Diff	t	Mean/Diff/	SD Diff	t
1	40	39.3	14.2	39.5[2]	15.1	-0.2	2.8	NS 0.4	2.2	1.7	*** 7.3
2	115	48.3	19.6	47.9	19.8	0.4	2.8	NS 1.4	1.9	2.0	*** 10.2
3	74	46.3	16.5	45.9	16.7	0.4	2.9	NS 1.1	1.5	2.5	*** 5.1
4	52	42.4	13.2	42.6[3]	13.3	-0.2	1.7	NS 0.8	1.3	1.08	*** 8.4
5	66	47.9	17.6	48.0	18.1	-0.26	2.1	NS 0.68	1.44	1.6	*** 7.3

Observers involved were - Miss Mckay - 1
Miss Webster - 3
Miss Grant - 2

Key:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

All measurements are in mm

Table 19(b)

Mean Values of "Total Skinfold" as Calculated by 2 Observers measuring the Same Subjects

Mean Difference, modulus Mean Difference, and Matched - Pairs t-tests are also included: FEMALES

Study Number	n	Observer I Mean	Observer I SD	Observer 2/3 Mean	Observer 2/3 SD	Mean Diff	SD Diff	t	Mean/Diff/	SD Diff	t
1	40	49.3	14.4	51.6[2]	17.3	-1.95	3.7	** 3.34	2.8	3	*** 5.9
2	94	57.7	17.5	58.7[3]	17.9	-0.95	2.9	** 3.2	1.8	2.4	*** 7.3
3	24	59.4	12.3	60.4	12.2	-1.06	2.7	NS 1.94	2.0	2.0	*** 4.8

Observers involved were - Miss McKay - 1
Miss Webster - 3
Miss Grant - 2

Key:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

All measurements are in mm

Reproducibility Results for February 1981

Circumferences and Diameters - Males

Measurements Site	N	Mean (1) Value	SD	Mean (2) Value	SD	$\overline{\text{Diff}}$	SD	SE Mean Diff	t	$\lvert\overline{\text{Diff}}\rvert$	SD	SE Mean Diff	t
Calf (cm)	42	37.9	2.5	38.0	2.5	−0.12	0.3	0.04	2.6^{*}	0.24	0.2	0.03	7.6^{***}
Thigh (cm)	46	56.5	4.1	56.6	4.1	−0.08	0.4	0.06	1.2^{NS}	0.34	0.2	0.03	9.5^{***}
Buttocks (cm)	46	95.5	5.6	95.9	5.7	0.02	0.6	0.09	0.2^{NS}	0.51	0.4	0.06	8.9^{***}
Upper Arm (cm)	49	29.5	2.4	29.6	2.4	−0.08	0.4	0.06	1.3^{NS}	0.34	0.3	0.04	9.2^{***}
Ulna (cm)	45	5.8	0.29	5.7	0.29	0.04	0.08	0.01	3.2^{*}	0.06	0.06	0.01	6.5^{**}
Tibia (cm)	45	9.8	0.49	9.8	0.48	0.00	0.1	0.02	0.26^{NS}	0.07	0.08	0.01	6.11^{***}
Biacromial (cm)	95	40.0	1.5	39.9	1.55	0.13	0.3	0.03	4.1^{***}	0.23	0.3	0.02	9.77^{***}
Biiliac (cm)	95	27.5	1.4	27.5	1.5	0.03	0.4	0.04	0.59^{NS}	0.33	0.3	0.03	11.2^{***}

Observer 1 - Miss McKay
Observer 2 - Miss Webster

Key:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

$\overline{\text{Diff}}$ = average difference between the two measurements, taking the (+) or (-) sign into consideration
$\lvert\overline{\text{Diff}}\rvert$ = average difference between the two measurements, taking no consideration of the sign

If the difference between the measurements of the two observers is not consistently in any one direction then $\overline{\text{Diff}}$ will approach zero. $\lvert\overline{\text{Diff}}\rvert$, however, shows the magnitude of the difference, no matter what the sign, and will always be larger than zero, unless both observers have identical measurements,

Reproducibility Results for February 1981

Circumferences and Diameters - Females

Measurements Site	N	Mean (1) Value	SD	Mean (2) Value	SD	$\overline{Diff}$	SD	SE Mean Diff	t	$\lvert\overline{Diff}\rvert$	SD	SE Mean Diff	t
Calf (cm)	17	36.5	1.6	36.6	1.6	-0.05	0.38	0.09	0.57 NS	0.28	0.26	0.06	4.40 ***
Thigh (cm)	17	57.1	3.6	57.6	4.0	-0.51	1.09	0.26	1.96 NS	0.85	0.84	0.20	4.14 ***
Buttocks (cm)	17	97.4	5.1	97.7	5.0	-0.29	0.91	0.22	1.31 NS	0.80	0.47	0.11	7.09 ***
Upper Arm (cm)	17	27.9	2.3	27.3	2.5	0.62	1.45	0.35	1.75 NS	0.73	1.39	0.34	2.12 *
Ulna (cm)	17	5.2	2.5	5.2	2.2	-0.04	0.09	0.02	1.95 NS	0.08	0.06	0.01	5.61 ***
Tibia (cm)	17	9.1	0.33	9.0	0.34	0.07	0.11	0.03	2.63 *	0.09	0.09	0.02	4.31 ***
Biacromial (cm)	47	36.3	1.5	36.1	1.7	0.18	0.53	0.08	2.37 *	0.38	0.41	0.06	6.33 ***
Biiliac (cm)	47	27.3	1.5	27.4	1.5	-0.07	0.33	0.48	1.56 NS	0.24	0.23	0.03	7.41 ***

Observer 1 - Miss McKay
Observer 2 - Miss Webster

Key:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

$\overline{Diff}$ = average difference between the two measurements, taking the (+) or (-) sign into consideration
$\lvert\overline{Diff}\rvert$ = average difference between the two measurements, taking no consideration of the sign

If the difference between the measurements of the two observers is not consistently in any one direction then $\overline{Diff}$ will approach zero. $\lvert\overline{Diff}\rvert$, however, shows the magnitude of the difference, no matter what the sign, and will always be larger than zero, unless both observers have identical measurements.

consistently took larger measurements than the other to any great extent. At the biacromial site, these differences were significant at the 99.9% level in males and 95% level in females but the SDs of 0.3cm and 0.5cm in the 2 sexes respectively, suggest that these were still relatively unimportant. The significant differences at the ulnar site in males and tibial site in females were also considered too small to be of importance.

The moduli, $|\overline{Diff}|$, of the diameters were significant at the 99.9% level at all sites, and had a maximum value of 0.38 $\pm$ 0.41cm at the biacromial site in females. In terms of a percent of the mean measurement however, the largest $|\overline{Diff}|$ occurred at the ulnar site in females, with a value of 1.5% and the smallest at the tibial site in males with a value of 0.7%.

Despite the significance of these differences, they were still of a similar magnitude to those found when 1 observer took repeat measurements and therefore were again considered to be relatively unimportant.

The circumference measurements demonstrated mean differences ranging from 0.02 to 0.12cm in males and 0.05 to 0.62cm in females, and this drop in reproducibility in females may reflect their higher fat contents. Subjectively, it was found to be more difficult to reproduce the circumferences in individuals with much subcutaneous fat or little muscle tone, because the measurement could be taken with the tape measure indenting the limb without the observer noticing. In more muscular or lean individuals the range of indentation possible was not so great. The higher reproducibility at the calf in females possibly reflected the relatively small fat deposits at that site.

The moduli of the Diffs ranged from 0.24 to 0.51cm in the males, and from 0.28 to 0.85cm in the females, being significant at the 99.9% level at all sites. As a percent of the mean measurement, the largest difference was 2.5% at the upper arm in females and the smallest 0.5% at the buttocks site in males.

This analysis suggests that although these differences were still relatively small, special care should be taken when measuring circumferences and particularly in females or 'plump' males, and at sites with relatively large subcutaneous fat deposits such as the upper arm.

2.8.4. Influence of Fat Content on Reproducibility and Accuracy of Skinfold Measurements

One of the problems encountered when using the skinfold method for assessing obesity is that with obese subjects it is often difficult to locate accurately the exact sites for measurement, and to standardise the measurement taken. One possible method for studying this problem is to allow more than 1 observer to take the measurements on each subject, and compare their results. As the percent body fat increases, there is a tendency for the difference between the measurement values of two observers on the same subject, to increase. We wished to examine how large and how important this difference was.

208 males between the ages of 16 and 56 years had skinfolds measured by 2 observers at the biceps, triceps, subscapular and supra-iliac sites. When taking the measurements, neither observer knew the measurement values found by the other observer.

The subjects were then divided into 4 groups of increasing fat content, according to the sum of the 4 skinfold measurements.

Group I Total Skinfolds < 27mm
Group II 27mm $\leq$ Total Skinfolds $<$ 43mm
Group III 43mm $\leq$ Total Skinfolds $<$ 66mm
Group IV Total Skinfolds $\geq$66mm

A description of the subjects in each group is shown on Table 21(a). Since the fat content tends to increase with age, it was an expected result that the average age increased as Group number increased. The increase in height with increasing fat content was not significant at the 95% level.

Using matched-pairs t-tests, the difference between the 'Total Skinfolds' values produced by the 2 observers were analysed in each of the 4 fatness groups Table 21(b).

As the group number increased, the mean value of 'Total Skinfolds' increased for both observers. The mean difference between the 2 observers ($\overline{\text{Diff}}$) and mean modulus of the difference ($|\overline{\text{Diff}}|$) also increased with

Description of 208 male subjects, grouped according to their Fat Content

Table 21 (a)

Group	No	Mean Age (Yrs) ± SD	Mean Height (cm) ± SD	Mean Weight (kg) ± SD
1	30	21.3 ± 5.0	175.1 ± 6.4	62.4 ± 6.1
2	72	21.1 ± 6.5	174.9 ± 6.1	65.8 ± 6.6
3	75	25.7 ± 8.2	176.0 ± 7.0	75.0 ± 8.0
4	31	27.5 ± 8.4	177.9 ± 6.8	84.8 ± 8.2

Reproducability of 'Total Skinfolds' measurements

between two Observers in four groups of Increasing Fat Contents: Males

Table 21 (b)

Measurement	Group	Observer 1		Observer 2		Mean Diff	SD Diff	t	Mean /Diff/	SD Diff	t
		Mean	SD	Mean	SD						
Total Skinfolds	1	24.7	1.98	24.3	1.84	0.37	1.5	NS 1.36	1.14	1.0	*** 6.3
Total Skinfolds	2	33.9	4.50	33.5	4.30	0.42	1.5	* 2.42	1.18	1.0	*** 10.3
Total Skinfolds	3	53.6	6.60	52.9	6.30	0.67	2.3	* 2.47	1.88	1.5	*** 10.4
Total Skinfolds	4	76.6	11.40	78.0	11.90	-1.37	4.1	NS 1.84	3.11	3.0	*** 5.71

All measurements are in mm

KEY: $p < 0.001$ - ***

$p < 0.05$ - *

increasing fat content. The mean $|\overline{Diff}|$ was significant at the 99.9% level in all 4 groups and increased from 1.14mm in Group I to 3.1mm in Group IV.

Groups I and II did not differ significantly from each other, in the reproducibility of 'Total Skinfolds' between observers 1 and 2. They were however significantly smaller at the 99% level from groups III and IV in mean $|\overline{Diff}|$, and with Group IV at the 95% level in $\overline{Diff}$. Groups III and IV differed significantly from each other in both $|\overline{Diff}|$ and $\overline{Diff}$ at the 95% level.

These results show that in male subjects with 'Total Skinfolds' of over approximately 43mm, reproducibility of skinfold measurements and therefore accuracy tended to become significantly more difficult. This decrease in accuracy became progressively worse, as 'Total Skinfolds' increased.

When fat content was calculated in all 4 groups the average $|\overline{Diff}|$ was approximately 0.5% fat and 95% of each group showed differences between observers of less than 1.5% of body weight. Since body weight increased as group number increased however, then the error in terms of fat mass did increase with increasing skinfolds totals. The magnitude of this 1.5% error was only 0.9kg in Group I and 1.3kg in Group IV and therefore group differences were still small and relatively unimportant. In practical terms therefore, when fat percent or fat mass was calculated there was no difference in accuracy between the 4 groups in this study.

2.9. QUESTIONNAIRE

Each subject was asked to fill out a questionnaire. The Forces questionnaire differed slightly from the civilian questionnaire in the 'Work Background' section. A copy of each is at Appendix F (1) and (2).

The questionnaire was divided into five sections:

(a) Personal background.

(b) Work background.

(c) Smoking habits.

(d) Health factors.

(e) Exercise Habits.

As each individual was examined, the observer looked over the questionnaire, checking that the question had been answered correctly, although occasionally some were left unanswered or incorrectly answered.

During the course of the survey, the Forces questionnaire had four important changes made to it:

1. Question 3 was changed from 'Places of Residence over the 10 years previous to joining the Services to 'Places of Residence over the first 15 years of your life'. We wanted to know the county in which each subject had spent most of his childhood, and therefore the second version of the question was considered to be more accurate. Since most of the Forces personnel joined when still in their teens however, their answers to the 2 versions of the question would in most cases be the same and therefore the 2 sets of answers were combined.

2. Question 24 changed from 'For how many months have you been carrying out this level of exercise?' to 'For how many months have you been carrying out this level of exercise/lack of exercise?'. These two changes were made from Male subject no. 854 and Female subject no 69.

3. Question 4 was added from Male Subject 857, Female subject 69.

4. Question 17 - The 5th answer box was changed from 'More than 20' to '21-25' cigarettes and an extra five possible answers were added. This change was made from Male subject 3174, Female subject 359.

The civilian questionnaire was unchanged throughout the survey.

2.10. ANALYSIS AND PROCESSING OF ANTHROPOMETRIC AND QUESTIONNAIRE DATA

2.10.1. General

The bulk of the analysis was carried out on an ICL 2976 computer belonging to Glasgow University. A Commodore Pet was used for statistical analysis involving less than about 100 subjects.

The information from each subject's completed questionnaire was coded and transferred on to a specially designed computer data sheet, as shown in Appendix G (2).

In order to keep the survey anonymous each subject was given a number which became Variable 1. The answers to the social information questions were coded and recorded as Variables 2 to 8 and 26 to 48 on sides 1 and 2 respectively of the data sheet. The anthropometric measurements from each subject were recorded on side 1 of the data sheet, as Variables 9 to 14 and 18 to 25. The sum of the four skinfolds was calculated by hand and entered as Variable 15. Using the equations of Durnin and Womersley (1974) a table was constructed which by taking the sum of the 4 skinfolds gave a value for the percent of the body weight accounted for by fat (percent fat) for both males and females separately.

For each subject, both the addition of the skinfolds and calculation of percent fat from the table, were double checked by the observers. Fat free mass, (in kg), (FFM), which is (body weight - fat mass) was calculated by the computer. Percent fat and FFM became Variables 16 and 17 respectively.

Once all this information was on the computer sheet, it was punched on to computer cards, ready to be read into the 2976 computer. Where answers were missing or obviously incorrect a 'missing value' code was used, and this answer was discounted from any analysis. A description of each of the 48 variables recorded is given in Appendix H.

The computer cards were read into the computer, in batches of about 200 subjects at a time, and all the information on them was listed on one printout. This was then checked for blanks and incorrect subject numbering.

Using the programs P1D and P2D from the program package 'Biomedical Computer Programs' (BMDP), available on the ICL 2976, checks were then made for extreme values of any measured variable, and any obvious incorrect coding of the questionnaire.

The computer sheet from every 50th subject was also checked against the original questionnaire for incorrect coding and against the computer printout to 'spot check' that the information from the data sheets had been correctly punched on to the computer cards. Any errors found using any of these checks were corrected on the data file, using the 2976 'ECCE' program, which permits data manipulation.

Throughout the survey data analysis was carried out using both the BMDP package of programs and 'MINITAB', an interactive statistical package (Ryan, Joiner and Ryan 1981). Minitab had the advantage that it was interactive while BMDP was not, but the disadvantage that it could not deal with all the data at once, because of the very large volume of the data.

2.10.2. Statistical Formulae and Abbreviations

Throughout the analysis, many statistical formulae and abbreviations were used. The less common ones, or those easily confused, are listed below.

1. Standard Error of the mean: $SE = \frac{SE}{\sqrt{n}}$

   SD = Standard Deviation
   n = no of subjects

2. Standard Error of the Mean Difference: $SE_{\bar{D}} = \frac{SD_D}{\sqrt{n}}$ - Used in matched pair analyses

   SD_D = SD of the differences between the pairs

   $$t = \frac{\text{Mean Difference}}{SE_{\bar{D}}}$$

3. Standard Error of the Difference: $SE_D = \sqrt{\frac{SD_1^2}{n_1} + \frac{SD_2^2}{n_2}}$ - Used in analysis of unmatched pairs

   $$t = \frac{\text{Difference between the Means}}{SE_D}$$

   SD & n_1 refer to sample
   SD_2 & n_2 refer to sample

4. Standard Error of the Estimate: $SE_E = \frac{\sum (y_i - \hat{y}_i)^2}{(N - p)^{1/2}}$

   $\sum$ = sum of
   N = No of cases
   P' = no of variables in the equation + the intercept
   $\hat{y}_j$ = predicted y for case j
   y_j = actual y for case j

5. Student - Neuman - Kuels Test (SNK Test)

This test was used after Analysis of Variance demonstrated in Section 3.2.10 that significant differences existed between group means and the question became, 'which group means were signficiantly different?' The test takes into account the order of the groups.

Unequal Sample Size

$$LSR = Q_{\alpha}(K,V)\sqrt{MS_{error}}\sqrt{\frac{n_1 + n_1}{2n_1 n_2}}$$

Key: V = degrees of freedom within the samples
K = 1 + difference in ranks between the groups being compared.
Q_{α} (K,V): from q table
MS error: error variance

The groups being compared were initally ranked from smallest to largest. In this way, a small difference between 2 adjacent groups would be more significant than the same difference between the non-adjacent groups.

The LSR is the smallest difference between the Means which is signficant at the 95% level.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. INTRODUCTION

This chapter is divided into 3 major sections, as described below. Section 3.2 is a general description and discussion of the anthropometric data from both the Forces and civilian samples, together with a comparison between the 2 sets of results. It also relates the results to Geographical area and social class and where possible a comparison between the Forces and civilians, the results and data from the OPCS (1981) preliminary report is included.

Section 3.3. describes the prevalence of obesity in the Forces and civilian samples.

Section 3.4. contains the development of the regression equations for the prediction of fat free mass in males and females and an estimation of their accuracy.

3.1.1. Anthropometric Differences related to Geographical Area

In order to examine anthropometric differences which may have been related to differences in geographical background, the Forces subjects were divided into groups according to the counties in which they had each lived during the first 10 years of their lives. If they had moved before the age of 10 years, it was taken as the county in which they had spent most of their first 15 years, but biased towards the early years. These years were considered to be the formative years and any individual who had spent this time outside the UK or moving between many counties in the UK, was discounted.

The counties were then grouped into Regions according to the grouping used by OPCS (Population Estimates, 1979. N. Ireland was also included. These regions are listed on Table 25, and each was given a number.

All the anthropometric means were calculated within each Region. Analysis of the differences between areas was carried out using an analysis of variance programme BMDPIV. Two-tailed t-tests were carried out between the individual group means. Where small differences in mean age occurred between groups, BMDPIV adjusted the anthropometric means towards values related to the average age, in order to remove any age related differences. These changes had only a very small effect on the final average figures.

The civilian subjects were divided into their respective geographical regions, as described in the Forces sample. Again, individuals who could not be assigned to one particular region were discounted from the analysis.

Because of the relatively low numbers in some regions, the regions were then grouped into 3 areas:

Area A: Scotland
Area B: North of England
Yorks and Humberside
North West England
East Midlands
West Midlands
Area C: London
South East England

Wales, N. Ireland, E. Anglia and S.W. England were totally excluded because their sample sizes were too small relative to the other regions. The regions were arranged as shown, both because of their obvious geographical associations and because the Forces results had shown the regions within the groups to have similar anthropometric measurements.

Analysis of variance and t-tests were not carried out on the civilian sample because it was not considered to be fully representative of the UK population distribution and the differences were small. Instead, trends were examined.

3.1.2. Anthropometric Differences Related to Social Class

The 5 standard Registrar General's social class (SC) categories were arranged into 4 groups in the OPCS (1981) survey analysis as shown below.

The Forces personnel were then put into SC's by taking the SC of their nearest equivalent civilian job. A list of this grouping is shown in Appendix I. Many of the Forces sample could not be allocated to a SC and therefore were discounted from this analysis.

The groupings of the 5 social classes into 4 groups for both the OPCS study and this study are shown below:

OPCS Grouping	Registrar General's SCs	Present Survey Grouping
1	I	1
1	II	1
2	III(nm)	2
3	III(m)	2
4	IV	3
4	V	4

It should be noted that the 4 SC groupings used in the OPCS and this study were not exactly the same at the lower end of the SC scale. When the 2 studies were compared directly the Forces and civilians were rearranged into the same groupings as used in the OPCS survey.

3.2. MEAN ANTHROPOMETRIC RESULTS: FORCES, CIVILIANS AND OPCS

The mean values for height, weight, percent fat and FFM, each bone diameter and each limb circumference were averaged within age groups, within the Forces and civilian, male and female samples. These results are presented in Tables 22 to 33 and Graphs 6(a), 6(b), 7(a) and 7(b) and are described below. A comparison between the Forces and civilian results is included and differences due to social class and geographical area discussed.

Most groups and sub-groups had fairly large sample sizes, but any with less than 10 subjects were not discussed in detail since it was believed that this sample size was too small to draw any conclusions. Because of the low number of females over 35yrs, only those between 17 and 34yrs were described in detail.

3.2.1. Height

(a) Forces Males: Table 22

Mean height varied between a minimum of 174.7cm and a maximum value of 176.5cm but there were no significant differences between the means of any two consecutive age groups over the age of 19y. The 16y olds however, were significantly smaller than all of the other age groups apart from the 40-44y olds and the 50-59y olds. The 17-19y olds were also significantly smaller than the 25-29y olds at the 95% level of significance. These significant differences in height found between the younger age groups compared to the older age groups were probably due to the fact that the younger age groups were still growing. As has been observed in many other cross-sectional studies (Montegriffo, 1968; Rosenbaum, 1954 and Kemsley, 1950) there was a small, steady decrease in mean height with age after age 29y, excepting the 45-49y group. There have been many suggestions put forward to explain these observations. The ageing process involving stature is, presumably, the result of shrinkage or compression of the intervertebral discs, osteoporosis, increasing curvature of the spine (Milne and Lauder, 1974) and an inability to stand erect but these operate mostly above the age of 60y. Factors such as arthritic lipping of articular margins and appositional bone growth (Lasker, 1953) may contribute also to age changes.

Within this study the changes in mean height between 29 and 49y were almost insignificant, but the decrease within the 50-59y group may have been influenced by the ageing process mentioned above. The secular changes in height which have occured within the past 60y may also have influenced these results.

(b) Civilian Males: Table 23, Graph 7(a)

Mean height throughout the age groups varied between the maximum value of 177.3cm to the minimum value of 174.3cm. There were no significant differences found between any of the age groups between 17 and 49y. However, the mean height of the 50-64y olds was significantly smaller than both the 20-24y olds and the 25-29y olds at the 99.9% level and significantly smaller than the 40-44y olds at the 95% level of significance. The inital difference in mean height was again probably due to the fact that the youngest age group was still growing, and the slight decrease from the age group 20-24y was similar to the decrease found in the male Forces sample.

(c) Male Comparison: Table 24

The differences between the means of the 2 samples ranged from 0cm to 1.4cm, and were significant only in the 20-24y group. In this group the civilians were significantly taller than the Forces at the 95% level by on average 1.1cm. This peak in the civilian mean height was however not significantly different at the 95% level from the means in the civilian age groups on either side and therefore the difference was probably an unimportant artifact.

(d) Influence of Geographical Area

(i) Forces and OPCS Males: Table 25

Mean height ranged between 173.8cm in N. Ireland and 177.7 cm in E. Anglia, a difference of 3.9cm. Areas 2,4,5,6,7 and 8 showed no significant differences in mean height between each other, but were significantly smaller at the 95% level than most other regions. Areas 9 to 12 also showed NS. differences between each other at the 95% level, but men from these areas were significantly taller than most of those in the 1st group. At the 95% level there were NS differences between Areas 1,2 and 3 but Area 1, Scotland, had significantly smaller values than all other regions except N. Ireland. N. Ireland did not show the same significant differences because of its relatively small value for n. Table 27 shows that within each region the Forces were on average taller than the OPCS (1981) sample. These populations differences ranged from 1.3-3cm and the SEs of the mean were similar.

(ii) Civilian Males: Table 26

Mean height increased from 175.1cm in Scotland to 175.4cm in Area B and 176.3cm in Area C.

(e) Influence of Social Class on Height: Forces, Civilian and OPCS (1981) Male Sample

The OPCS were divided into social classes as described in section 3.1.2. Since OPCS did not quote numbers within each SC/age group, they could not be included in the tables. Table 28 shows the mean value for height within each of these 4 social class and age groups for the OPCS (1981), Forces and civilian samples. Because of the small sample sizes in the other groups, only SC groups 1 and 2 (i.e. I, II and III (nm) in the Registrar General's classification) were discussed when the 3 population samples were being compared. In addition, only the age range 16-49yrs was examined because of the low values for n beyond these ages, and only groups with at least 10 subjects were discussed.

As explained in section 3.1.2, the social class grouping used in the OPCS survey was not the one favoured in this study. As a result, Table 29(a) shows the Forces and civilian subjects grouped in a slightly different form from Table 28. Only the arrangement of the lower 2 social classes differed in Table 29(a) but since there were now more than 10 subjects within each age group in the group 3 (i.e. III(m) and IV) civilians aged between 20 and 59y, they were included in the discussion of differences between the Forces and civilian samples. Within group 4 only the 50-59y old group had over 10 subjects.

Within SC I and II the Forces males were on average 1cm taller than the civilians and across the age groups these differences ranged from 0.7cm to 1.5cm. Within SC III (nm) however the overall difference was only 0.1cm although between age groups the mean differences ranged from 0.2cm to 2.0cm. Within Group 3 on Table 29(a), the Forces still tended to be taller than the civilians and this was significant at the 95% level in the 45-49y group.

Throughout the social classes, in all but 3 groups, the Forces were also on average taller than the OPCS sample, with differences ranging from 0.2cm to 4.9cm. The statistical significance of these differences was not tested since values for the SD had not been provided in the OPCS preliminary report from which the results were taken. The mean values for the 16-49y age range were also not quoted in the OPCS data.

In SC groups I and II the civilian and OPCS (1981) results were similar, with neither sample being consistently taller than the other. The range of differences was from 0.2cm to 2.1cm, which was about half the range between the OPCS and Forces groups. In SC III(nm) the average results were again similar.

Between the SC groups, the decrease in mean height with decreasing SC seen in the civilian and Forces sample, was even more evident in the OPCS sample. Within any age group and population sample the maximum decrease was 6cm found between groups III (non-manual) and (IV and V) in the 45-49y olds. There are, however, some discrepancies. For example, in the OPCS survey, several age groups do not show this relationship.

Overall, neither the civilian nor the OPCS (1981) results were consistently larger than each other and therefore they were relatively similar to this extent. The tendency for the Forces sample to be on average slightly taller than both samples but the OPCS sample in particular, does not appear to be related to geographical area. Section (d) demonstrated that an individual's area of origin could make a small difference to his height. Since about 32.5% of the Forces and civilians combined, but only 21% of the OPCS sample came from Scotland, Wales, N Ireland and the North of England, and these regions tended to have smaller mean heights than the southern regions, then it is unlikely that geographical origins explain much of the differences. It therefore appears that the Forces male personnel may represent a slightly different type of population than the OPCS sample.

One obvious explanation for the height differences is that the Forces selection procedure takes height into account. This is described and discussed at the end of this section.

(f) Forces Females: Table 30, Graph 6(b)

Mean height varied between a maximum value of 164.1cm for the 20-29y olds and a minimum value of 160.1cm for the 30-34y olds. It increased significantly at the 95% level between the first two age groups, remained steady between the ages of 20 and 29y and then decreased significantly to the 30-34y old age group. This decrease in mean height made the 30-34y olds significantly smaller at the 99.9% level than the 3 younger age groups, but the increase again in the older age groups suggest that the fall was due to a sampling error.

The significant increase in height between the first two age groups was again as with the males, probably due to the fact that growth had not stopped.

(g) Civilian Females: Table 31, Graph 7(b)

Mean height throughout the age groups varied between the maximum value of 163.4cm and the minimum value of 160.7cm. There were no significant differences in mean height between the ages of 20y and 49y. However it did increase significantly at the 95% level between the 17-19y olds and the 20-24y olds and also decreased significantly at the 95% level from the 45-49y olds to the oldest age group, making the 50-64y olds significantly smaller than all the other age groups, apart from the age group 35-39yrs. As with the males, the difference between the first two age groups was probably due to an increase in growth and the decrease to the age related deterioration.

(h) Female Comparison: Table 32

There were no significant differences between the 2 samples beyond the age of 30y, probably because of the lower sample sizes beyond that age.

Between the 2 samples, the differences in mean height for the 17 to 29y age groups ranged from 0.7cm to 1.7cm and were significant at the 95% level in the 25-29y group only. The Forces means were greater than the civilian values, and the differences were of a slightly greater magnitude than those in the male results despite their general lack of significance.

(i) Influence of Geographical Area

The subjects were divided into geographical areas as described in Section 3.1.1.

i) Forces and OPCS Females: Table 33

Mean height ranged between 161.5cm in Scotland, and 165.5cm in the S. East. a variation of 4cm. Areas 1 to 6 and 8 to 10 showed no significant differences at the 95% level. The E. Midlands however, had a significantly larger mean than Scotland, Wales, the N. West and the W. Midlands at this level. The mean in the S. East region was also significantly higher at the 95% level than the North and higher at the 99% level than Scotland, Wales, Yorks and Humberside, the N. West and the W. Midlands. There was therefore a slight grouping of regions into northern and southern groups, with the northern groups being on average slightly smaller.

In a similar fashion to the male results, within each region the female Forces sample were on average taller than the OPCS (1981) sample, and these differences ranged from 1.5 to 4.1cm. Values for the SE mean were larger in the female Forces groups however, mainly due to their smaller sample sizes. Table 34.

ii) Civilian Females: Table 26

Mean height rose steadily from Area A to Area C by on average 1.1cm.

(j) Influence of Social Class on Height: Forces, Civilian and OPCS (1981) Female

Two social class groupings were used as described in section 3.1.1. Because of low sample sizes, the civilian subjects within SCs III(m), IV and V were not described on Table 35 but were included in Table 36. Again groups with sample sizes less than or equal to 10 were also not described.

Within SCs I and II ages 17-49y, there was no difference in the overall mean height between the civilian and Forces sample, but in III(nm) the Forces mean was 1.2cm greater than the civilians. There was not enough data to compare the other social class groups.

On average the OPCS (1981) sample were slightly smaller than the Forces sample throughout all the SCs with differences ranging from 0.2 to 6.3cm but it was not possible th assess the significance of these results because of the lack of values for the SDs in the OPCS data.

The SC I and II civilians were on average slightly taller than their OPCS equivalents. Within SC group III(nm) the pattern was similar to the male results in that neither the civilian nor the OPCS samples were consistently larger than the other. Differences between means ranged from 0.1cm to 2.0cm and the overall means were about the same. The exact value could not be calculated for the OPCS sample because there was no OPCS mean value for height in the age range 17-49y quoted.

Between the SC groups, there was no obvious pattern in mean height in the Forces or civilian samples, possibly due to small sample numbers. The OPCS (1981) sample however showed a slight decrease in mean height from SC I to IV and V but this was not as obvious as the decrease found in the male sample. Within any age group, the largest fall in mean height was 3.3cm, found in both the 20y and 30-34y age ranges, between SC groups (I and II) and (IV and V).

These results suggest that there may be a slight class difference in height in females which is independent of age, but it was not obvious in either the Forces or civilian samples.

In conclusion, in common with the male results, it is not known precisely why the mean Forces heights were sometimes higher than the OPCS and civilian results although it probably again represents a bias in the selection process for services personnel. Differences in height distributions are discussed in section 3.2.2.

3.2.2. Comparison of the Height Distribution of the OPCS (1981) and Forces sample

The results in earlier sections have shown that within most sub-groups the Forces sample have tended to be on average slightly taller than the OPCS sample but fairly similar in height to the civilians. Within the male sample the 3 means were 173.8cm, 175.6cm and 175.9cm for the OPCS, civilians and Forces samples respectively. Within the female samples these 3 values were 160.7cm, 162.4cm and 163.6cm.

In this section, the height distributions of the Forces and OPCS samples were further described and compared and possible reasons for the differences put forward. The civilians were not included in this analysis because it was known that their sample was not fully representative of the

UK population and therefore their height distribution was not expected to be the same as the OPCS sample.

(a) Males

Table 37 and Graph 8(a) describe these distributions for the entire Forces and OPCS male samples. The distribution of the Forces sample with the Household Cavalry and Footguards excluded is also shown on Table 37.

Graph 8(a) suggests that the Forces height distribution is shifted about 2cm right of the OPCS distribution producing means of 175.9cm and 173.8cm for the Forces and OPCS samples respectively. The general shapes of the 2 distributions were similar and are discussed below.

Forces Height Selection

At the lower end of the distribution, the shift was probably in part caused by the minimum height limits imposed by the Forces, as only about 2% of the Forces as opposed to 4% of the OPCS sample were below 162.6cm.

In the Army, most Regiments and Corps stipulate minimum required heights of 60" (152.4cm) or 62" (157.5cm). The Household Cavalry and Footguards however have a minimum of 68" (172.7cm) and since the Forces sample included 249 males, i.e. almost 5%, from these regiments this would affect the height distribution to a small degree. Once the Household Cavalry and Footguards were excluded, the mean height was only reduced by 0.4cm to a value of 175.5cm and the overall distribution was hardly changed. If the Army sample alone minus the Guards and Household Cavalry were examined however, their mean height was found to drop from 175.4cm to 173.8cm which was the same as the OPCS sample mean.

The RAF also apply minimum height limits to certain occupations as described below.

(a) MT drivers: 157.5cm

(b) RAF Policemen: 172.6cm

(c) RAF Policewomen: 162.5cm

(d) Gunner: Age 17½y 163.5cm
Age 18y 165cm
Age 19y or over 166.0cm

(e) Firemen: Age 17½y 162.5cm
Age 18y 165.0cm
Age 19y or over 166.0cm

(f) Loadmasters: Between 157.5-190.5cm.

About 200 males within the RAF sample held these trades and therefore their mean height must have been influenced by these restrictions.

Royal Navy restrictions on height are 155cm for those aged 17½y or less, 157.5cm up until 21yrs and 160cm, for those over 21y of age. Since the removal of the 249 Guardsmen and Cavalry all of whom were over 172.7cm only reduced overall mean height by 0.4cm, the removal of these individuals on a height basis would not have brought the mean height down to the OPCS value.

Altogether, these height specifications did have an influence on the height distributions within the 3 Service samples, and probably largely account for the differences in mean height between the 3 Services i.e. 175.4cm - Army, 176.0cm - Navy and 176.1cm - RAF. Apart from the Guards and Household Cavalry the Army selection was least orientated towards tall individuals, therefore their mean was the lowest of the three. The high baseline for all RN entrants and the relatively high minimum heights in selected RAF trades, which accounted for about 10% of this RAF sample, pushed up both of their mean values and shifted the distributions on the graph slightly to the right.

It therefore appears that the height selection procedures accounted for much of the difference between the OPCS and Forces height distributions and in the Army at least it appeared to account fully for the difference.

<u>Age Distribution</u>

Another contributing factor to the height differences was the different age distributions of the two samples. One percent of the Forces sample was over 50y old compared to about 26% of the OPCS sample, and since mean height fell from 173.6cm to 170.4cm between the OPCS 45-49y and 60-64y groups, this difference in the age distributions must have been instrumental in reducing the OPCS mean height. In addition, a related but more minor point is that the Forces sample only reached a maximum age of 59y compared to the maximum of 64y in the OPCS sample. Within matched age groups however the mean differences in height was still about 1.5cm.

Social Class Distributions

The social class analysis showed a tendency in both the Forces and OPCS samples for height to decrease with decreasing SC. Although only about 20% of the Forces came from the SC groups I, II and III(nm) the distribution of the OPCS sample throughout the groups was not known and therefore a comparison could not be made. If the OPCS survey had less than 20% of its sample in these top 3 SC groups, the net effect would probably be to reduce their overall mean height slightly below the Forces value. Within SC and age groups however, the Forces still tended to be slightly taller but the differences were reduced to an average of about 1.3cm. This small reduction from the value of 1.5cm seen within age groups alone, suggest that SC had little bearing on the differences in the height distributions.

Geographical Area Distribution

The geographical area analysis showed that area had a slight influence on height, with the northern areas tending to be slightly smaller than the southern areas. Table 3 shows the geographical distribution of the Forces and OPCS samples (the OPCS sample distribution = mainland UK population distribution), and the main differences were the undersampling from the south and slight oversampling from the northern regions in the Forces sample. These differences were relatively minor except in the London area and Scotland, and would act to reduce the Forces mean below the OPCS value. They therefore do no account for the Forces being taller.

Methodological Differences

In both the present and the OPCS studies the method as described by the IBP Handbook minus the supported head stretch, was used, i.e. subject standing back against the stadiometer, heels together, arms by side, head in the

Frankfort plain position. The OPCS study asked subjects to 'stand as tall as you can' while in this study subjects were asked to 'stand straight and take a deep breath'. It is unlikely that this small difference in methodology would cause any difference in overall results.

Equipment

OPCS used a collapsible stadiometer, incorporating a head bar on a friction lock i.e. when moved up, it stayed in position. This study used a self assembly stadiometer which came in four parts:

1. Base Plate. 2. 2 x metre bars. 3. Head bar.

Both types of stadiometer did not measure to the ground, thus their accuracy was checked before and during the surveys.

Subject Selection Procedures used by the Interviewers

As explained in the methods section and Table 1, about 2.5% of the male Forces sample were selected because they were either between 5'-5'3" or over 6' tall. This would have had some influence on the final height distribution but this influence is not easily quantified. The breakdown of the 2.5% into tall and small proportions is not known. Even if 2.5% of the individuals over 6' (183cm) were removed from the sample there would still be 14.3% of the Forces and only 10% of the OPCS sample, over 182.6cm tall.

In conclusion, it appeared that the Forces distribution was shifted about 2cm right of the OPCS distribution mainly because of its younger age distribution, the height selection procedures in the Forces, and the height selection procedures employed by the interviewers. Differences in social class distribution were probably of minor importance as were methodological differences. Differences in geographical area distribution would have acted to decrease and not increase the differences.

When all these points were combined they appeared to account for most, and possibly all, of the differences in height between the OPCS and Forces male samples.

(b) Females

Table 37 and Graph 8(b) describe the height distributions for the Forces and OPCS female samples. The lower ends of the 2 graphs are similar and the main difference between them appears to be that the Forces had a slightly lower percentage of its distribution between 160 and 167.5cm, together with a slightly larger proportion over 175cm. It was probably these latter individuals who brought the Forces mean to 163.6cm, (about 3cm taller than the OPCS mean) since apart from these two differences the two distributions were fairly similar.

In the Army, the minimum height requirement for WRAC is in most cases either 58" (147.3cm) or 62" (157.5cm) depending on employment. The WRNS set a general minimum of 58" (147.3cm) except for the following trades.

(a) M/T Drivers: 64" (162.6cm)

(b) Air Mechanics: 61" (154.9cm)

(c) Training Support Assistants: 60" (152.4cm)

Only 9 WRNS fell into these 3 trades and therefore would make little difference to the overall sample. The WRAF appear to have no minimum height except for 162.5cm for policewomen of whom none were seen.

Overall these minimum limits did not appear to make much difference to the Forces height distribution and in fact the smallest individuals were in the Forces sample.

There was therefore no obvious reason for the differences between the two distributions since there was no selection of the female sample on the basis of height which could account for these changes. Any differences due to the older age distribution in the OPCS sample would have been expected to shift the complete Forces distribution to the right, which was not the case. As in the male samples, social class and geographical area were of little importance.

The uneven shape at the right side of the Forces distribution suggests that there may have been a bias in the sampling procedure which accounted for much of the difference between the means. Without this bias the Forces and OPCS distributions would be very similar.

3.2.3. Weight

(a) Forces Males: Table 22

Mean weight increased by a total of approximately 15kg throughout the age groups. Up until age group 30-34y, the increases between age groups were significant at the 99.9% level. Between the ages of 30 and 49y mean weight continued to increase slightly despite some slight decrease in mean height between age groups. In this age range, however, the increases were no longer significant between any two consecutive age groups. Mean weight was seen to fall slightly to the oldest age group but again this was not a significant decrease. Since mean FFM was also seen to generally decrease from the 25-29y age group onwards, the increase in weight from the same age group was due mainly to the increase seen in % body fat with age.

(b) Civilian Males: Table 23

Mean weight throughout the age groups increased by a total of 9.5kg. Over the first 3 age groups it increased significantly at the 95% and 99% levels from 65.9kg to 72.9kg and from age 25y to 49y mean weight increased by another 3.5kg but the increases between consecutive age groups were not significant. It was then seen to fall slightly to the oldest age group but not significantly so. The inital increase seen was probably largely a reflection of the increase in mean height and therefore FFM, however the further increases with age were not height related and most have reflected variations in body fat since both mean height and FFM were seen to decrease after the age of 29y. Since mean percentage fat increased with age, the slight decrease in mean weight for the 50-64y old males was due mainly to the significant decrease in mean FFM at this age.

(c) Male Comparison: Table 24

There were significant differences at the 95% level and above between the 2 samples at all ages from 20y upwards, ranging from 2.3kg to 4.4kg, and the Forces were consistently heavier than the civilians in all age groups.

Since these differences were greater than the differences in mean FFM, they must have been due to both FFM and fat mass differences between the samples.

(d) Influence of Geographical Area

(i) Forces Males: Table 25

Mean Weight ranged between 71.7 kg in N. Ireland and 74.7 kg in both E. Anglia and London, a range of 3 kg. At the 95% level, the N. Ireland mean was significantly smaller than the means in both E. Anglia and London; Scotland was significantly smaller than the W. Midlands, the S. East, E. Anglia and London; the London mean was significantly larger than the means in Areas 5 and 6. There were no other significant differences.

(ii) Civilian Males: Table 26

Mean weight varied by 1.4kg, rising from Area A to B, but falling again in Area C. These changes reflected both FFM and percentage fat changes.

(e) Influence of Social Class on Weight

The preliminary OPCS (1981) results did not include information on weight related to social class and therefore only the Forces and civilian samples are compared here. Table 29(b).

Within all the SC and age groups, except the 17-19y group Vs, the 20-24y group Vs and the 25-29y group (III(m) and IV) the Forces mean weight was greater than the civilian mean weight. These differences ranged from 0.2kg to 8.4kg (average 2.8kg) and were significant in 8 groups. From the results of sections 3.2.4. and 3.2.5. it can be concluded that these differences were due mainly to variations in mean FFM as opposed to % fat.

Between SC groups, mean weight either increased with decreasing SC or stayed fairly constant.

(f) Forces Females: Table 30

Mean weight did not differ significantly over the first 4 age groups, but varied between 58.7kg for the 30-34y olds and 61.5kg in the 20-34y group. The low value for mean weight in the 30-34y group was probably mainly a reflection of the low height and subsequently FFM in the group.

(g) Civilian Females: Table 31

Mean weight increased gradually throughout the age groups by a total of 7.5kg. The increase between consecutive age groups was found to be significant only between age groups 17-19y and 20-24y. From the ages of 17y to 34y mean weight increased by approximately 2kg only compared to the 7kg increase for civilian males over this age range. Mean weight for the females then increased by approximately 5.5kg between the ages of 34-64y. As with the males the initial increase in mean weight with age was due mainly to the increase in mean height and latterly due to the increase in body fat with age. Compared to the male total weight gain of approximately 9kg this suggests that women have a tendency, especially between the ages of 17-34y, to gain slightly less weight with age than men over a similar period. However, the reverse was seen in the age range 34-64y in that women gained more weight than the men.

(h) Female Comparison: Table 32

At the 99.9% level, the Forces had larger average weights than the civilians, and these differences ranged from 4.2kg to 5.0kg. Since FFM changes could not account for all these differences, they must have been due to both FFM and fat mass variations between the samples.

(i) Influence of Geographical Area

i) Forces Females: Table 33

Mean weight varied between 57.3kg in N. Ireland and 63.7kg in London. These two regions were also the lightest and heaviest in the male sample. At the 95% level, London and the S. East had significantly larger mean values than Scotland, the North and N. Ireland. Again this pattern of differences was similar to that found in the male sample.

ii) Civilian Females: Table 26

Mean weight rose from 58kg in Area A to 59.7kg in Area C, reflecting both an increase in FFM and a slight increase in fat mass from 16.7kg to 17.4kg.

(j) Influence of Social Class on Weight: Forces and Civilians Female samples. Table 36(b)

With the exception of the 20-24y olds in group (III(m) and IV) in each SC and age group the Forces females were heavier than the civilians. Considering only groups with at least 10 individuals the differences ranged from 1.0kg to 7.0kg and the mean was 3.5kg. Later sections' results suggest that these differences were due to variations in both percent fat content and FFM between the samples. It can be seen then that in most groups the larger component in the weight difference is FFM, which includes both differences in height and 'build'.

Between the SC groups there were 2 significant differences. The 17-19y old civilians in SC group III(nm) were 6kg lighter than those in groups I and II while the 25-29y old Forces in SC groups III(m) and IV were 5.2kg heavier than those in Groups I and II both differences being significant at the 95% level. Overall however, there was no general pattern to the differences.

3.2.4. <u>Comparison of Mean Weight in Height and Age Groups Between the OPCS (1981), Civilian and Forces sample</u>

In a further examination of the differences between the Forces, civilian and OPCS (1981) samples, all 3 populations were divided into height and age groups. Tables 38(a) and 39(a) give mean value for weight within these groups, but no statistical analysis of differences have been calculated, because of the absence of statistical information in the preliminary analysis of the OPCS sample.

Earlier analysis in section 3.2. had suggested that differences in 'build' existed between civilian and Forces samples. The preceeding section suggested that these differences could also exist between the OPCS, Forces and civilian samples, but height differences often made comparisons difficult. It was hoped that analysis within age and height groups might help clarify this point. Again, groups with sample sizes less than or equal to 10 were not included in this description.

(a) Male Results: Table 38(a)

Since the oldest age groups in the three surveys encompassed different age ranges, the OPCS and civilian samples ranging from 50 to 64y and the Forces from 50 to 59y, the 3 sets of results could not be directly compared. Within these oldest age groups, the OPCS and civilians had higher mean ages than the Forces sample and their mean weights tended to be lower, reflecting either a lower fat content or a decrease in FFM with age. Also there were no 16y olds in the civilian sample.

The age and height groups described are those chosen in the OPCS (1981) survey analysis.

Between the ages of 16y and 39y, in 9 out of the 14 groups the order from heaviest to lightest was Forces, OPCS then civilian sample although there was often little difference between the OPCS and the Forces. In the remaining 5 groups the order varied but the Forces sample were never the lightest.

Between 40y and 64y the civilian sample was again the lightest in 8 out of 10 groups but the order between the Forces and OPCS sample varied.

Within the first height range i.e. upto 170cm, the differences between the means in any 1 age group ranged from 0kg to 5.3kg. With some exceptions the Forces mean was usually larger than the OPCS mean, possibly partly due to a difference in the height distributions. In this height range almost 8% of the Forces sample were below or equal to 160cm in height, while almost 20% of the OPCS sample were in this category. About 26% of the civilian sample within this first height group were below 160cm also, and the OPCS - civilian differences were reduced to 0.8kg-3.6kg.

Within the tallest age range i.e. $>$180cm the Forces sample were consistently the heaviest and in 4 out of 5 groups the civilians were again the lightest. The differences within one age group ranged from 0.8kg to 6.1kg. The reasons for the Forces result may again be partly due to differences in the height ranges, as excluding the oldest group about 8% of the Forces sample who were over 180cm were actually over 190cm and about 2% were over 193.5cm. Less than 6% of the OPCS sample and 1.5% of the civilian sample who were over 180cm were also over 190cm however, and none of the OPCS and only 2 of the civilians were over 193.5cm tall. The differences between the OPCS and civilian sample means nevertheless still held a maximum of 5.3kg.

Within the remaining 14 height/age groups, the differences in mean ranged between 0.1kg and 5.7kg, and excluding the oldest group this range was reduced to a maximum of 5.4kg. Between the Forces and OPCS sample the maximum was only 1.8kg. Between the civilian - Forces, and civilian - OPCS, however, these values were 4.4kg and 5.4kg respectively.

In conclusion therefore, it appears that within a limited height and age range the mean weights for the OPCS and Forces samples were similar although the Forces means tended to be about 1.5kg heavier. On the other hand, the civilian sample tended to be lighter than both OPCS and Forces samples by on average about 3kg.

In section 3.2.6. it is shown that within the same age/height groups, the mean difference in FFM between the Forces and civilian samples is about 2.5kg. This suggests that the differences in weight described here were mainly a reflection of height independent differences in FFM as opposed to variations in percent fat. The differences in social class distribution between the 2 samples described in the preceeding sections and the tendency for the lower SC to be heavier because of higher fat contents in those below 30y of age was probably also contributary.

(b) Female Results: Table 39(a)

Once again there were 2 age ranges in the oldest age group in the female sample, as the OPCS and civilian samples both extended to 64y while the Forces only reached 54y. Since there were also only 5 Forces subjects in this age range it was not possible to compare their results. There were no 16y old Forces subjects, a fact which was probably contributory to making the youngest Forces group on average heavier than their OPCS counterparts. There were only 6 civilian 16y olds in total and hence they probably had only a small effect on mean weight.

Excluding the oldest age groups, in 11 out of the 16 height/age groups the order from the heaviest to the lightest sample was again Forces, OPCS then civilian. Of the remaining 5 groups, 3 showed the civilians to be the lightest, as did 4 of the oldest age groups when the Forces were not included. Overall however, the low numbers in many of the female groups made it difficult to come to many conclusions. Any groups with sample sizes less than or equal to 10 were not included in the remainder of this discussion.

Within the first height range for each age group the differences between the means of the 3 samples varied from 0.4kg to 4.9kg. These differences were slightly influenced by differences in the minimum heights of the 3 groups. None of the OCPS sample were below 150cm while 15% of the civilian and 9% of the Forces sample were smaller than this. These differences would tend to make the civilians on average slightly smaller than the other 2 groups. The youngest Forces age group in this height range and all other height ranges had a larger mean weight than the OPCS sample probably due to their lack of 16y olds. The male 16y olds were on average about 2kg lighter than the 17-19y olds of the same height, and a similar trend was seen in the females.

Within the tallest height range the Forces sample were again the heaviest and differences between means ranged from 0.2kg to 5kg. Still within this height range, about 21% of the OPCS and civilian samples and 27% of the Forces sample were over 175cm tall and therefore different height distributions probably account for very little of the difference between the Forces and the other 2 samples. There was a tendency in both the smallest and tallest height ranges for the civilian means to be closer to the OPCS than the Forces means.

Of the remaining 14 groups, 13 showed the civilians to be the lightest and 9 out of the 11 groups with data from all 3 samples, showed the Forces as the heaviest. Differences between means within any height/age group ranged from 0.1kg to 5.4kg. Between the Forces and OPCS samples and between the Forces and civilian samples the maximum differences were 3.9kg and 5.4kg respectively. The civilian and OPCS samples however produced maximum differences of only 2.4kg and again there was a slight tendency for these 2 samples to be more similar to each other than to the Forces sample.

In conclusion, it was found that within the stated height and age groups the mean weights of the Forces sample tended to be greater than both the civilian and OPCS samples and the civilian sample tended to be the lightest. These differences must have been due to differences in 'build' and percent fat. This result is similar to the findings in the male samples. Unlike the male results however, the OPCS means were very slightly and possibly not significantly, closer to the civilian than Forces results. The overall average difference between the civilian and Forces means was about 3.4kg. The results in the preceeding section suggest that these differences are unlikely to be related to the different SC distributions between the samples.

Summary

In both the male and female samples, within limited height and age groups, the Forces tended to be heavier than the civilians by on average about 3kg. The male OPCS sample had weights similar to but slightly lighter than the Forces sample, while the female OPCS results were about mid-way between the Forces and civilians.

Although a few of these differences could be accounted for by slight differences in the height distributions of the samples, most must have been due to differences in either the fat content or 'build' of the samples. Information on FFM within height/age groups was available only in the Forces and civilian samples, and was examined in section 3.2.6.

The results obtained however suggest that once slight differences in height distribution were taken into account the male Forces sample was fairly representative of a British random sample and that conclusions drawn from it, with any relevant corrections, may be applicable to the British population. It was not possible to draw this conclusion from the female results but differences between the 3 samples were generally not large.

3.2.5. Percent Fat

(a) Forces Males: Table 22

Mean percent fat over all the age groups, varied by approximately 14%. Up until age group 30-34y, it increased significantly at the 99.9% level. Between the ages of 30 and 39y it remained steady but increased significantly at the 99.9% level to 24.6% in the 40-44y olds. The increase from the 40-44y olds to the 45-49y olds was not significant. It reached a maximum of 27.2% within the oldest age group and this 1.7% increase was significant at the 95% level.

(b) Civilian Males: Table 23

Mean percent fat increased from 14.8% in the youngest age group to 26.8% in the oldest age group, a total increase of 12% for the male civilian sample. The increases found between age groups were significant at the 95% level and above, apart from the first two age groups and the 30-34y olds and 35-39y olds.

(c) Male Comparison: Table 24

Differences in percent fat varied from 0.1% to 1.2% between the 2 samples but were only significant at the 95% level, in the 40-44y and 45-49y groups. Since mean weight was significantly higher in the Forces sample fat content in kg was also higher in the Forces sample. The 20-24y olds and the 30-34y olds, who had shown significant weight differences between the 2 samples at the 99% level, did not show significantly different percent fat values, and mean fat mass varied by less than 1kg between the samples within these 2 age groups. This suggests that fairly large FFM differences existed, and were largely responsible for the weight differences.

(d) Influence of Geographical Area

i) Forces Males: Table 25

Percent fat ranged from 17.7% in the S. West to 18.6% in Wales, a range of 0.9%. The only significant differences between regions were between the S.West and Wales, Scotland and the North, with the S.West having a significantly smaller mean at the 95% level.

ii) Civilian Males: Table 26

Percent fat in the civilian sample remained fairly steady between Regions A and B and fell by 0.8% fat to 20.9% in Area C.

(e) Influence of Social Class: Forces and Civilians Male Samples: Table 29 (c)

Within each SC and age group, there was no significant differences between the Forces and civilian mean fat contents, and neither sample had consistently higher results than the other. The differences ranged from 0.0% to 2% of body weight.

Between the social classes, there was a tendency in the age groups below 29y for percent fat to increase significantly as SC decreased. Significance levels are marked on Table 29(c). This pattern was seen in both the civilian and Forces samples and the maximum significant mean difference was 2.3%. Beyond 30y, there were no significant differences between social classes and there appeared to be no relationship between SC and percent fat. These results are similar to those of Silverstone (1970), who found an increased prevalence of obesity as social class decreased, between 20-29y but not between 40 and 59y of age.

(f) Forces Females: Table 30

Mean percent body fat increased only slightly over the first 4 age groups from 28.0% to 29.7%. The only significant increase was between age groups 25-29y and 30-34y.

(G) Civilian Females: Table 31

Mean percent body fat increased from 25.2% for the 17-19y olds to 35.7% for the oldest age group, a total increase of 10.5% for the female civilian sample. The increases in percent fat were significant at both the 99% and 99.9% levels and were only significant between decades and not within a decade. Again there was seen to be an approximate increase of 3% body fat for each decade from the age of 20y. The female civilians sampled between the ages of 17-34y gained on average only 3.1% bodyfat whereas the male civilians gained on average 5.8% over the same age range. This suggests again that females in their earlier years are possibly more weight conscious than their male contempories and attempt to keep their weight down to the level of their early 20s.

(h) Female Comparison: Table 32

The Forces sample had larger means for percent fat, significant at the 99.9% level in the 17-19yr and 20-24yr groups. These differences ranged from 0.9% to 2.8% or about 1.7kg to 2.9kg and therefore accounted for about half the weight variation between the 2 samples.

(i) Influence of Geographical Area

i) Forces Females: Table 33

Mean percent fat varied between 25.9% in N. Ireland and 29.6% in London. There was few significant differences at the 95% level except that the E. Midlands had a significantly smaller mean than London and Wales; N. Ireland showed a significantly smaller mean than Wales, Yorks and Humberside and London, and finally the mean in the S. East was significantly less than in Wales.

ii) Civilian Females: Table 26

Fat as a percent of weight, remained roughly constant throughout the 3 regions.

(j) Influence of Social Class: Forces and Civilian Female samples. Table 36(c)

Within each SC and age group the Forces sample had higher average fat contents than the civilian sample. These differences varied between 3.8% and 0.3% and averaged 1.7%. Using a student's t-test for unmatched groups, it was found that these differences were significant within groups I and II, and III(nm) in ages 17 to 24y at the 95% level or above. Again, larger sample sizes would be required in order to see any pattern in the older age groups.

A pattern between the SC groups was not obvious in either the Forces or civilian samples. Percent fat tended to fall as SC decreased in the 17-19y and 35-39y groups, and this was significant at the 95% level in the 17-19y old Forces females. It also fell significantly by 1.2% between SC groups (I and II) and III(nm) in the 20-24y old Forces women. In all other groups, the pattern was reversed and average percent fat increased as SC decreased, but this was only shown to be significant between groups (I and II) and (III(m) and IV) in the Forces 25-29y olds. The studies of Silverstone (1970) and Baird et al (1974) both showed an increase in obesity with decreasing SC within the age ranges 20-59y and 15-65y respectively.

3.2.6. Fat Free Mass

(a) Forces Males: Table 22

Mean FFM increased by 5.3kg from 56.5kg for the 16y olds to 61.8kg for the 25-29y olds. The increase between the first 3 youngest age groups was significant at the 99.9% level, and probably influenced by the parallel height increases. The peak value in the 25-29y group was then followed by a decrease significant at the 99.9% level to 60.3kg for the 30-34y olds. Mean FFM remained steady in the 30's but fell significantly at the 99.9% level to 58.7kg for the 40-44y olds. There were no significant differences between the age groups over 40y. The mean FFM values for the 16y olds and the 50-59y olds were both significantly smaller at the 99.9% level than the mean FFM values of those aged between 20 and 39y. These changes in mean FFM with age are discussed more fully in a later section.

As with the changes in mean height it is difficult to know whether these FFM changes were of a cross-sectional or longitudinal nature.

(b) Civilian Males: Table 23

Mean FFM increased by 4kg from the 17y olds to the 29y olds. This increase which was found to be significant at the 95% level, was then followed by a significant decrease at the 99% level of approximately 1.5kg for the 30-34y old age group. Mean FFM did not differ significantly until the oldest age group, where it decreased again by 2kg to 55.1kg. As with the Forces data, these increases and decreases in mean FFM within age groups were influenced by the changes seen in height with age. Change in height may not have totally accounted for them however.

(c) Male Comparison: Table 24

The differences between the 2 sample means varied between 1.6kg and 2.8kg and were significant in all age groups over 20y at the 99% or 99.9% levels. The Forces had consistently higher means than the civilians. Since it had been shown that these differences were not totally due to differences in height, they must have been due to differences in 'build', where 'build' reflects muscle and skeletal dimensions relative to height. Although the 17-19y old Forces subjects also had a higher mean FFM than the civilians, it was not significant at the 95% level.

(d) Influence of Geographical Area

i) Forces Males: Table 25

Mean FFM varied between 58.2 kg in N. Ireland and 60.9 kg in East Anglia, a range of 2.7kg. These were also the regions with the smallest and largest values for mean height. Areas 2 to 8 showed NS differences between each other at the 95% level,as did areas 9 to 12, but there were many significant differences between those 2 groups, with the southern group tending to have larger mean values than the northern. Areas 1,2,3,5 and 6 also showed no NS difference at the 95% level. Overall, the changes in mean FFM reflected changes in mean height and Scotland tended to show many significant differences because of its relatively large sample size.

ii) Civilian Males: Table 26

Mean FFM rose from 57kg in Scotland to 57.6kg in Area B, but fell to 56.9kg in Area C.

(e) Influence of Social Class: Forces and Civilian Male Sample. Table 29(d)

In 23 of the 27 comparable SC and age groups, the Forces sample had higher mean values for FFM. These differences ranged from 0.2kg to 5.7kg but averaged only 2kg and were significant in 9 groups as shown in Table 29(d). In most groups the differences were not large. The results from the previous sections suggest that the differences were in part due to differences in mean height, but the relatively large magnitude of some of these FFM variations suggest that they may also reflect differences in skeletal muscle and 'build', between the 2 samples.

Between the social classes, there were significant increases as well as decreases in FFM as SC decreased, in both the civilian and Forces samples. Most of these variations, however, reflected differences in mean height between the groups. It is therefore suggested that between groups matched for height, there would be little difference in mean FFM between the SC in either sample.

(f) Forces Females: Table 30

Mean values for FFM increased slightly from 43.4kg in the 17-19y olds to 44kg in the 25-29y olds. This was then followed by a significant decrease of 2.9kg to 41.1kg in the 30-34y olds. This latter decrease was probably, however, mainly a reflection of the significant decrease in mean height from the 25-29y to the 30-34y group, and also probably of sampling bias.

(g) Civilian Females: Table 31

Mean FFM varied by approximately 3kg throughout the age groups and was seen to increase significantly at the 99.9% level, between the 17-19y olds and the 20-24y olds. Until age 49y FFM remained fairly steady but then decreased significantly at the 99% level for the oldest age group. Again this rise and decrease found in the mean FFM was probably partly a reflection of the variation in mean height with age.

(h) Female Comparison: Table 32

The Forces mean FFM values were greater than their civilian equivalents by values from 1.9kg to 2.3kg and were significantly different in all groups between 17-29y at the 99.9% level. The differences in height must have accounted for some or all of these FFM differences, especially in the 25-29y group and therefore it was difficult to determine whether differences in 'build' existed between the 2 population samples.

(i) Influence of Geographical Area.

i) Forces Females: Table 33

Mean FFM varied between 42.3kg in N. Ireland to 44.6kg in the S. East, and the differences between regions reflected to some extent, the differences in mean height. Again the mean in the S. East was significantly higher at the 95% level than the mean in Scotland, the N. West and W. Midlands. At this level, Scotland also had a significantly smaller value than both London and the North

ii) Civilian Females: Table 33

Mean FFM rose steadily by a total of 0.9kg from Area A to C.

(J) Influence of Social Class: Forces and Civilian Female Sample. Table 36(d)

With the exception of the 17-19y olds in SC (I and II) and the 20-24y olds in SC groups (III(m) and IV) within each SC and age group the Forces females had higher values for mean FFM than the civilians. The differences ranged from 0.4kg to 3.7kg, had an average of 1.4kg, and were significant in 4 of the age groups below 29y, as shown in the table. From the results in the previous section, it is likely that these differences were partly due to differences in mean height, but were likely also to reflect some differences in 'build' i.e. skeletal and muscle mass, between the 2 samples.

There was no obvious pattern of change between the SC groups and where there were significant differences, as in the 17-19y and 20-24y old civilians, these seemed to mainly reflect differences in mean height.

3.2.7 Comparison of Mean FFM and % Fat in Height and Age Groups Between the Forces and Civilian Sample

The civilian and Forces male and female samples were grouped according to their height and age as shown in Tables 38 and 39, (b) and (c). It was found that by removing height differences, differences between other variables such as 'build' became more clear. FFM and % fat were calculated in each group. Weight was also analysed within these groups and was described in section 3.2.3. in a comparison with the OPCS results. Only males between 17 and 49y old were analysed since there were no 16y old civilian males, and the age range in the over 50y olds varied between the samples. Females over the age of 39y were also excluded because the numbers in the Forces sample were too small for statistical analysis. Male and female groups with samples less than or equal to 10 were not included in the discussion.

(a) Male Results

In 33 of the 37 height/age groups the Forces' mean FFM was greater than the civilian equivalent, and in 15 of these groups this difference was significant between the 95% and 99.9% levels. Overall differences ranged from 0kg to 5kg, and averaged approximately 2.5kg. This mean difference was only 0.5kg below the mean difference in weight which had been found between the 2 samples within the same groups and is described in section 3.2.4.

In 24 of the 37 groups the Forces sample had a larger percent body fat than the civilians, but these differences were only significant in 6 groups and in one additional group the civilians were significantly fatter than the Forces at the 95% level. The overall differences ranged between 0.1% and 4.6% with an average of about 1.2% fat.

In conclusion, it appeared that most of the differences in weight within height/age groups between the Forces and civilian samples were due to differences in FFM as opposed to percent fat. The Forces population appeared to have larger 'builds' as had been suggested in section 3.2.3. Although section 3.2.4. shows that the weights of the populations measured by OPCS were similar to the Forces results the conclusion cannot be made that they also have larger 'builds' than the civilian sample in this study, since no information on their body composition i.e. fat and FFM contents, was available.

The importance of these 'build' differences and of taking them into account becomes obvious in section 3.4 where regression equations to predict FFM were developed from the Forces sample. Independent variables which reflected 'build' relatively independent of height or percent fat had to be included in the regresssion in order to make them accurate for both the Forces and civilian population samples. These 'build' differences were therefore useful because they reduced the population specificity of the final prediction equations by presenting two different populations which both had to be catered for in the regression analysis.

It is hoped that the inclusion of the 'build' factor in the regressions allows them to be accurate on populations with builds different from both the civilian and Forces sample within this study, but further cross-validation will be required to answer this question.

(b) Female Results

In 18 of the 20 female height/age groups the Forces mean FFM was greater than the civilian equivalent and in 8 of these groups these differences were significant between the 95% and 99.9% levels. The overall range of differences was from 0.1 to 3kg and averaged 1.6kg.

The Forces females had a greater mean body fat content in 17 out of the 20 groups, significant between the 99% and 99.9% levels in 6 groups. Overall the differences ranged from 0.1% to 3.5% and averaged 1.8%, a slightly smaller range but a larger mean value than in the male sample. 1.8% of the weight of a 60kg female would be approximately 1.1kg.

The overall mean difference in weight between the Forces and civilian samples was about 3.4kg which could not be accounted for by either differences in FFM or percent fat alone. Since most of the groups which demonstrated significant differences in percent fat also showed significant FFM differences, it appears that the differences in weight were probably due to both factors and that neither was obviously more important than the other. Although most of the significant differences were found in the younger age group this is more likely to reflect the greater numbers in these groups than any age related effect.

Any differences in 'build' which existed between the 2 population were small and did not seem to be of any great importance in either this or the regression analysis.

3.2.8. <u>Bone Diameters and Limb Circumferences</u>

(a) Forces Males: Tables 40(a) and (b)

i) Bone Diameters

The average results for the 4 bone diameters measured on the male Forces sample are shown in Table 40(a). There were many small but significant age related changes. Mean ulnar diameter increased by 0.2cm throughout the age groups. The two increases in mean values occurred between the age groups 25-29y and 30-34y, and 35-39y and 40-44y and were significant at the 99.9% level. These figures were however rounded off to 1 decimal place and the increase was in fact more gradual. Mean tibial diameter also varied by 0.2cm throughout the age groups. The differences that occurred between age groups were significant at the 99.9% level.

Mean biacromial diameter varied by 1.6cm over all the age groups. The mean value increased significantly at the 99.9% level by 1.2cm from the 1st to the 3rd age group. Thereafter it increased by 0.4cm in total but the increase was not significant between any two consecutive age groups. However, the resulting mean biacromial diameter for the 45-49y olds was significantly larger than the mean values given for those younger than 25y. From the 45-49y to the oldest age group mean biacromial diameter decreased by 0.5cm, but this was not a significant change. This diameter appeared to be reflecting the changes in mean height described in section 3.2.2.

Mean bi-iliac diameter increased continuously throughout the age groups by a total of 2.6cm. This site had the largest percentage increase of all the individual sites. The mean values increased significantly at the 95% level or above over the first 5 age groups. It then continued to increase, but only significantly so between the age groups 40-44y and 45-49y, at the 99.9% level. The overall increase in bi-iliac diameter with age appeared to be more a reflection of % fat changes than height or FFM.

The increases seen with age in mean bi-iliac diameter are in agreement with several authors i.e. Marquer and Chamla (1961), Parot (1961), Wessel et al (1963) and Susanne (1971). These previous authors had also noted slight changes with age in biacromial diameters till 55 years of age, followed by large decreases after this age. However, the continued increase found over the older age groups, especially in the case of the bi-iliac diameter might have been due to errors involved taking the measurement. With increasing age generally, subcutaneous fat also increases and as a result of this the difficulty in being able to measure the actual bone diameter minus the underlying tissues also increases. This may have a tendency to affect the resulting mean values within age groups since an increase in mean bi-iliac diameters would arise with an increase in age and percent body fat.

ii) Limb Circumferences

The average results for the four limb circumferences in age groups are shown in Table 40(b). Mean upper arm circumference increased by a total of 4.7cm over all the age groups. It increased gradually with age and significantly so at the 99.9% level between the first 5 age groups. The mean circumference remained steady between the ages of 30 and 39y but this was followed by significant increases at the 95% level of 0.3cm amd 0.4cm, reaching a maximum of 31.9cm in the 45-49y group. This was then followed by a slight but significant decrease at the 95% level to 31.5cm for the oldest age group. These changes appeared to reflect more the changes in percent fat and weight than FFM or height.

Mean calf circumference varied overall by only 1.6cm and increased by 1.5cm over the first 4 age groups. Between each age group these increases were significant at the 95% level or above. The circumference remained fairly steady between the ages of 29y and 49y followed by a slight but not significant decrease for the oldest age group. Despite this slight decrease, mean calf circumference in the 50-59y olds was still significantly larger than that of the 16y olds and the 17-19y olds at the 95% and 99.9% levels of significance respectively. These changes reflect changes in FFM more than percent fat or weight.

Mean thigh circumference increased by approximately 4cm from 53.7 to 57.6cm over the first 5 age groups and these increases were significant at the 99.9% level between groups up to the 29y olds. The mean circumference then stayed steady within 0.5cm until the 45-49y groups, after which it decreased to 56.5cm in the oldest age group. The differences were not significant between any two consecutive groups beyond 30y of age. Again, despite the decrease in mean thigh circumference from the 45-49y to those over 50y of age the oldest age group still had a significantly larger mean at the 99.9% level than those under 19y. This pattern of changes again appeared to reflect more the changes in FFM than in percent fat.

Mean buttock circumference was seen to increase gradually with age by 8cm in total. This was the largest proportionate increase at any site in terms of cm. Over the first 5 age groups the increases were significant at the 99.9% level. Thereafter mean buttock continued to increase but only significantly so at the 95% level between the age groups 40-44y and 45-49y. This continuous gradual increase in size was similar to that found at the upper arm site and again appeared to reflect the increase in percent fat and weight with age.

The initial increases from ages 16y to 29y for all four mean limb circumferences were a reflection of the significant increases seen in both percent fat and FFM in the younger age groups. From age group 25-29y to 45-49y mean upper arm and mean buttock circumference continued to increase, whereas mean calf and thigh circumference remained fairly steady. Overall, mean upper arm and buttock circumferences appeared to be more influenced by % fat than were the calf and thigh circumferences. The slight decreases found in all four mean circumferences for the oldest age group were likely to be due to to the decrease in mean height and 2kg decrease in mean FFM for this age group.

(b) Civilian Males: Table 41(a) and (b)

i) Bone Diameters

The average results for the four bone diameters from the male civilians, in age groups are shown in Table 41(a).

Mean ulnar diameter varied by a total of 0.3cm over all the age groups. Although the differences between age groups were very small they were significant. The very small but gradual general increase with age was not obviously a relection of changes in either FFM or percent fat.

Mean tibial diameter for the male civilians varied by only 0.1cm over all the age groups, and was significant at the 95% level only between age groups 20-24y and 25-29y. The pattern between 20y and 39y was more similar to FFM than percent fat patterns.

Mean biacromial diameters varied by 0.7cm over all the age groups. Apart from the significant drop at the 95% level between the 45-49y group and the oldest age group which appeared to reflect the fall in mean height at that age, there were no significant differences found between any of the other age groups. The overall pattern of change appeared to be most reflective of height changes.

Mean bi-iliac diameter varied by 2.6cm over all the age groups. At the 95% level mean values differed significantly between the ages of 17y and 29y and then remained steady until the age of 39y. It then increased again at the 95% level over the following age groups.

These changes were mainly influenced by similar changes in percent fat and the reason why these 2 variables were so highly associated was that with fat individuals it was difficult to push away all the subcutaneous fat from the bi-iliac measurement site.

i) Limb Circumferences

The average results for the male civilian limb circumferences, in age groups, are shown in Table 41(b). The mean upper arm circumference increased by a maximum of 3cm over all the age groups. It increased gradually with age and significantly over the first 3 age groups. Thereafter the mean values remained within 1cm of one another. These changes appeared to reflect the changes in percent fat and weight rather than FFM or height.

Mean calf circumference varied overall by only 1.7cm and increased significantly at the 95% level over the first 3 age groups to 38.0cm. Thereafter it decreased slightly but by only 0.5cm in total. These changes again appeared to reflect the changes in FFM more than percent fat or weight.

Mean thigh circumference increased significantly by 3.1cm over the first 3 age groups. Thereafter it gradually decreased by 2.2cm in total. This intial increase and decrease in circumferences with age again appeared to reflect the changes seen in FFM rather than percent fat.

The mean buttock circumference increased gradually with age by a total of 6cm. This again was the site where the largest proportionate increase in terms of cm was found. The inital increase of 4.6cm over the first 3 age groups was significant but thereafter the increases were very slight. This gradual increase was again similar to the increase found at the upper arm site and appeared to reflect the changes in weight and percent fat with age rather than FFM.

(c) Male Comparison: Table 42

i) Bone Diameters

A comparison of the matched Forces and civilian age groups, demonstrated many small but significant differences between the mean bone diameters in the 2 samples. These significant differences ranged from 0.1cm to 0.3cm, and in all groups except the biacromial diameter in the 20-24y olds the Forces mean was larger.

Ulnar diameter demonstrated significant differences at the 99% and 99.9% levels, in all groups except the 17-19y, 25-29y and 50y groups. Tibial diameter differed significantly in all groups except the 17-19y olds and 40-49y olds. The only significant difference in biacromial diameter was at the 95% level, in the 20-24y olds, and there were no significant differences in bi-iliac diameter between the 2 samples.

The differences in 'build' between the 2 samples therefore, appeared to be reflected in small differences in the ulnar and tibial diameters and the possible importance of these differences is discussed later.

ii) Circumferences

The differences between the mean upper-arm measurements in the 2 samples ranged from 0.9cm to 1.6cm, and were significant in all age groups, at the 95% level and above. In all groups, the Forces mean exceeded the civilian equivalent.

The Forces average calf circumference was greater than the civilian circumference by between 0.1cm and 0.7cm, but was significantly greater only at the 95% level, in the 20-24y olds and 30-34y olds.

Differences in thigh circumference varied from 0.5cm to 1.7cm and were significant at the 99% or 99.9% levels in all groups except the 17-19y and 25-29y olds.

Mean buttock circumference differed by between 0.1cm and 1.8cm between the 2 samples. Again, the Forces means were greater than the civilian's and these differences were significant in all groups at the 95% and 99% levels, except for the 17-19y, 25-29y and 40-44y olds.

Conclusion

From these results, it was not possible to come to many conclusions about relationships beteen these circumferences or bone diameters and height, weight, FFM or % fat, because of the inter-relationship between variables, i.e. the correlation between buttock and FFM was about 0.81, and between upper-arm and FFM was only 0.68, but it was the arm and not the buttock circumference which showed a pattern of significant variations which were similar to FFM variations.

(d) Influence of Geographical Area

i) Forces Males: Table 43(a) and (b)

There were many small differences, significant at the 95% and 99% levels. Ulnar diameter was 5.85cm in areas 2 to 8, and 5.90cm in areas 9 to 12 and depending on the number of men, some members of the latter group had significantly larger means than the former group. The largest mean difference was however only 0.14cm.

The changes in mean tibial diameters followed the same basic pattern, with Areas 2 to 8 tending to form one group and Areas 9 to 12 another group. Biacromial diameter showed little significant change between regions with the exception that E. Anglia had a significantly higher value than all other areas, and Scotland a significantly lower value than all other areas except Wales and N. Ireland. Biiliac diameter did not vary significantly between Areas 1 to 7, or between Areas 8,10,11 or 12. Again however, the southern group tended to have many significantly higher means than the northern group.

There were no significant differences between the areas at the 99% level, except that Scotland had a significantly smaller mean calf and buttock measurement than London. The relatively small sample size in E. Anglia, a region with similar mean values to London, prevented these significance levels existing also between E. Anglia and Scotland. At the 95% level, London had significantly higher mean values than Scotland, the S. West and N. Ireland for thigh and buttock circumference; a significantly larger mean calf than N. Ireland and a significantly larger mean thigh than the S. East. Scotland had a significantly smaller mean calf and buttock circumference than the East Midlands and E. Anglia respectively.

There were no significant differences in the mean arm circumferences at the 95% level.

ii). Civilian Males: Table 44(a) and (b)

Mean ulnar diameter rose by 0.1cm, from 5.8cm in Area A to 5.9cm in Areas B and C, while tibial diameter did not vary at all between the 3 areas.

Biacromial diameter followed the same pattern as weight, rising by 0.2cm from 40.4cm in Area A to 40.6cm in Area B then falling to 40.3cm in Area C. Biiliac diameter on the other hand showed variations similar to percent fat, remaining constant between Areas A and B and falling slightly in Area C.

The largest difference in the means between the 3 areas, at any site, was 0.9cm between Areas B and C at the thigh circumference site. At the calf site, mean values were about steady between Areas A and B while at the other 3 sites there was a slight increase in measurement. At all 4 sites there was a slight fall between Areas B and C.

(e) Forces Females: Tables 45(a) and (b)

The average results for the 4 bone diameters are shown in Table 45. Taken to one decimal place, the mean ulnar diameter was the same for all 4 age groups under 35y old.

Mean tibial diameter varied by only 0.3cm between 8.9cm and 9.2cm over the first 4 age groups and the differences were significant at the 99.9% level. There was no age related pattern of change however.

Mean biacromial diameter within the first 4 age groups varied by only 0.2cm, but this time the differences were not significant. Again there was no pattern related to age.

Mean bi-iliac diameter increased significantly at the 99.9% level between the first two age groups, but between the ages of 20 and 34y it remained about constant.

The fall in the mean bi-iliac, tibial and possibly biacromial diameters within the 30-34y group was probably greatly influenced by the low mean height in the same age group and sampling bias.

Because of the low sample sizes in the older age groups it was difficult to explain further these results but they are discussed in more detail in the female civilian section.

The average results for the four limb circumferences within each age groups are shown in Table 45(b).

Mean upper arm circumference varied by only 0.4cm over the first 4 age groups and none of the differences were significant.

The first 3 age groups had similar mean calf values but there was a significant decrease at the 95% level to the 30-34y group. This decrease made the calf circumference significantly smaller at the 99.9% level in the 30-34y olds than in the 17-19y olds, but this was again probably an artefact of the sample and reflected the low height and FFM in this age group.

Mean thigh circumference varied between a minimum of 56.3cm in the 30-34y group and 57.4cm in the 20-24y group. These changes were not significant and generally reflected the overall changes in mean weight.

Mean buttock circumference increased significantly at the 99.9% level from the 1st to the 2nd age group and then showed a non-significant increase over the next two age groups. The slight decreases in mean circumferences, for the 30-34y olds was again probably a reflection of the decrease in the mean height and FFM values.

(f) Civilian Females: Tables 46(a) and (b)

The average results for the four female civilan bone diameters in age groups are shown in Table 47(a).

Mean ulnar diameter increased by 0.3cm throughout the age groups, and as with the male results, although the differences were small they were significant. The diameter increased significantly at the 99.9% level by 0.1cm at age 20-24y and remained steady until age 40-44y where it increased significantly at the 95% level by 0.1cm. There was a final increase of 0.1cm to the oldest age group and this was significant at the 99% level. In reality the increases did not occur in 'jumps' but in this analysis the figures were 'rounded' off to 1 decimal place.

Mean tibial diameter varied by 0.3cm throughout the age groups. The increases and decreases found in the younger age groups were all significant at the 95% level.

The initial drop in mean ulnar and tibial diameters between the 1st and 2nd age groups were probably a reflection of the similar drop in mean height. Thereafter the very gradual changes in ulnar diameter did not obviously reflect percent fat or FFM changes, while the tibial increase beyond about 29y suggested that it was most influenced by percent fat changes.

Mean biacromial diameter varied by 1.4cm over all the age groups. There was a slight but significant decrease at the 95% level during the mid twenties but thereafter there were no other significant decreases or increases between consecutive age groups. The steadiness of this measurement was more reflective of FFM and height patterns than percent fat.

Mean bi-iliac diameter varied by 1.8cm over all the age groups and was seen to increase gradually with age. The differences were significant at the

99% level between both the 17-19y olds and 20-24y olds and between the 30-34y olds and 35-39y olds. The increase seen in mean bi-iliac diameter during the mid forties was also significant at the 95% level. Again bi-iliac diameter appeared to be more influenced by percent fat changes than by FFM changes.

The average results for the female civilian limb circumferences in age groups are shown in Table 46(b).

Mean upper arm circumferences increased by 3.1cm in total from age 17 to 64y. The increase was gradual, was not significant between any consecutive age groups and reflected mainly the pattern of change in mean weight and possibly percent fat.

Mean calf circumference varied by only 0.9cm between the maximum and minimum mean values. It decreased slightly between the ages of 17 and 34y and then gradually increased till age 49y. For the oldest age group mean calf circumference was seen to decrease slightly but at no stage were the variations significant between consecutive age groups. This pattern of change appeared to reflect changes in both FFM and percent fat but possibly the latter had the greater influence.

Mean thigh circumference varied by 1.8cm between the minimum and maximum mean values. The mean increased significantly at the 99% level between the 17-19y olds and the 20-24y olds. Thereafter mean thigh circumference varied by 0.7cm over the remaining age groups but again the variation was not significant between any two groups and reflected mainly FFM changes.

Mean buttock circumference increased gradually with age. The increase of 1.8cm between the 17-19y olds and the 20-24y olds was significant at the 99.9% level and the increase of 3.5cm at mid thirties was significant at the 95% level. As with mean calf and thigh circumferences there was a slight but non-significant decrease in mean buttock circumference for the oldest age group. The magnitude of the increase at this circumference site suggests again that it was mainly influenced by the parallel increase in percent fat, but the fall between the 2 oldest groups demonstrates that it was also influenced by height.

(g) Female Comparison: Table 47

There were few significant differences in bone diameters between the 2 samples, and except for bi-iliac diameter in the 45-49y olds where the difference was 1.2cm, these differences ranged from 0.2cm to 0.4cm. Again, the Forces mean tended to be larger than the civilian equivalent.

Ulnar diameter showed no significant differences at the 95% level except between the over 50y groups. This result differs from the male sample, where most groups showed significant differences.

Tibial diameter differed significantly at the 95% or 99.9% levels in all groups except those between 30y and 44y, but this lack of significance was probably influenced by the relatively small sample sizes in these groups.

In a similar manner to the male results, there were few significant differences in mean biacromial or bi-iliac diameters and because of their small magnitude, the differences which did exist were not considered to be important.

At all circumference sites, the Forces were always greater than the equivalent civilian means when a significant difference was demonstrated. Differences in mean upper arm circumference between matched groups ranged from 0.3cm to 2.3cm and were significant in the age groups below 39y, at the 95% or 99.9% levels.

Unlike the male sample, there were many significant differences in mean calf measurement. All groups below 39y, except the 30-34y olds, demonstrated these differences at the 95% or 99.9% levels, and significant and non-significant differences ranged from 0.2cm to 1.6cm.

Thigh circumference showed significant differences between the same groups and at the same levels as calf, and also between the over 50yr olds at the 95% level. Throughout all the age groups, these differences in mean between the 2 samples ranged from 0.1cm to 4.8cm.

Buttock circumference differences ranged from 2.1cm to 3.8cm, and were significant at the 95% or 99.9% levels in the 3 groups below 29y.

These differences between the 2 samples were on the whole greater than differences found in the male sample, and in both samples the Forces means tended to exceed the civilian equivalent.

Conclusion

It was concluded therefore that the Forces sample was slightly taller than the civilians and was significantly heavier between the ages of 17-29y. This weight difference was due to both FFM and fat mass differences but it was difficult to determine whether there were any differences in 'build' between the samples. As mentioned in the male sample, it is difficult to differentiate between changes in circumference and diameter measurements which reflect FFM or percent fat changes.

(h) Influence of Geographical Area

i) Forces Females: Table 43(a) and (b)

In a similar fashion to the male sample, there were many small but significant differences between regional means. Ulnar diameter showed a maximum significant difference of 0.1cm between the W. Midlands and S. East regions, at the 99% level. At the 95% level, the S. East also had a significantly larger mean than the S. West, Yorks and Humberside and Scotland; the W. Midlands had a significantly smaller mean than the S. West and E. Midlands. Unlike the male sample, the mean in Scotland was not significantly less than most other regions.

Tibial diameter ranged from a mean of 8.9cm in N. Ireland to 9.2cm in the S. East, a difference significant at the 95% level. Again at this level, the S. East had a significantly greater mean than Scotland; N. Ireland had a significantly smaller mean than the North, Yorks and Humberside and the E. Midlands.

Biacromial diameter ranged from 35.8cm in the W. Midlands to 36.6cm in London, a significant difference at the 95% level. At this level, the W. Midlands mean was also significantly less than the means in the North, the E. Midlands, the S. East and the S. West; Scotland had a significantly smaller mean than the E. Midlands, the S. East and the S. West; the S. West had a significantly larger mean than the N.West.

Biiliac diameter ranged from 27.2cm in N. Ireland to 28.1cm in London, but this difference was not significant at the 95% level. The W. Midlands mean was however significantly smaller at the 95% level than the means in Areas 4,5,10 and 11. There were the only significant differences at the 95% level.

At the 99% level, there was no significant differences between the 12 Geographical areas. At the 95% level, the only significant difference in the mean arm circumferences was between Wales and the E. Midlands, the former having the larger measurement. There was no obvious pattern in the remaining significant differences, except that Scotland and N. Ireland tended to have lower means than most other regions while London and Wales tended to have larger values.

ii) Civilian Females: Tables 44(a) and (b)

Mean ulnar and tibial diameter did not change between the 3 areas. Biacromial diameter again reflected changes in weight by increasing from Area A to B then C while bi-iliac diameter reflected the percent fat pattern and stayed about constant.

3.2.9. <u>Summary</u>

In both the male and female samples there was little change in mean height with age but in both male samples there was a slight increase from 16 or 17y to the 20-24y group, which was probably a reflection of the fact that the boys had not yet reached their full skeletal growth potential. The same pattern was not obvious in the females possibly because they reach skeletal maturation at a younger age. From the mid-20s or early 30s onwards, height remained steady in both sexes but there was a mean decrease of over 1cm in all 4 samples between the 45-49y olds and the oldest group. This was probably a reflection of the general ageing process.

Mean weight rose fairly steadily with increasing age in all groups and in term of kg this rise was about twice as great in the males when compared to the female sample.

Mean percent fat also rose with age, but whilst in the males this increase was fairly steady with about half the total increase before and half after the 30-34y group, in the females fat content was fairly steady until about 29y and thereafter it increased much more sharply.

Mean FFM in the males rose steeply to a maximum in the 25-29y olds and thereafter fell away more gradually until the oldest group were at about the level of the 17-19y olds.

These overall changes were reflected in both the circumference and bone measurements but because of the intercorrelations between all the variables it was not possible to state that any circumference or diameter reflected only percent fat or FFM as they all reflected a bit of both. General tendencies can however be pointed out.

Both the ulnar and tibial diameters showed very small gradual increases with age but neither was obviously reflecting FFM or percent fat changes. Biacromial diameter on the other hand, tended to reflect mainly height changes and thus also FFM changes more than percent fat. Because of the tendency for subcutaneous fat to be deposited around the hips, bi-iliac diameter tended to be influenced by percent fat in both sexes. It was often difficult to take the measurement accurately in fat individuals.

In both males and females the general tendency was for the calf and thigh circumferences to be more influenced by FFM while the upper arm and buttocks reflected percent fat changes better.

These relationships become reinforced in later analysis when independent variables are chosen to predict both percent fat and FFM in the 2 sexes. The differences in 'build' between the two male populations appeared to be reflected mainly in differences at the ulnar, tibial, upperarm and thigh sites, with the Forces having the larger means.

When producing regression equations from the Forces sample which could also be applied to the civilians, these results would suggest that at least one of the 4 measurements mentioned above should be included in order to provide a measure of 'build'. As is shown in a later section this was found to be the case, and ulnar diameter was included in the male regression equations because it not only reflected 'build' but also was relatively poorly correlated with percent fat.

In the male analysis it was suggested that ulnar diameter was an indicator of 'build' which was fairly independent of fat content. The lack of significant differences at the ulnar site in most female groups suggests that their 'builds' may have been fairly similar, and that FFM differences may have been mainly due to height differences.

When applying regression equations calculated on the female Forces sample to the civilians, it is shown in a later section that any anthropometric differences between the 2 populations did not appear to have much importance. The equations worked equally well on both populations.

Both the civilian and Forces samples demonstrated small differences in anthropometric measurements between the various geographical regions and areas. A quantatative comparison cannot be made between the Forces and civilian samples from the data presented. Qualitative analysis is more appropriate, becâuse the progamme BMDPIV adjusted the anthropometric means for any differences which were age related, with the result that the 2 samples ended up with anthropometric values which were appropriate for the mean ages within the Forces and civilian samples respectively. Since the mean age in the Forces and civilian samples differed, the latter having the higher value, this caused differences between the samples, such as higher fat contents in the civilian sample.

Both samples showed Scotland to have one of the lowest values for height, but while the Forces males tended to show London and S.E. England to have larger means for most other measurements, in the civilian sample this situation was reversed at most sites. In the civilian males, the North of England group of regions tended to have the largest anthropometric means. Since the civilian sample was not very representative of the U.K. population however, the Forces results may be more appropriate.

Both female samples showed a tendancy for the order of magnitude of the means to go in ascending order from Scotland to the northern England regions and finally to the southern England regions.

In both samples, male and female, the regional differences were small and

MALES

Mean Results within Age Groups: FORCES — Table 22

(Standard Deviation in Parenthesis)

n = 5331

Age (Yrs)	n	Height (cm)		Weight (kg)		% Fat		FFM (kg)	
16	370	174.7	(6.5)	65.5	(7.8)	13.4	(3.1)	56.5	(5.8)
		*		***		***		***	
17-19	1057	175.7	(6.8)	68.2	(9.0)	15.4	(4.0)	57.4	(6.1)
		NS		***		***		***	
20-24	1274	176.2	(6.9)	72.7	(10.0)	16.6	(4.6)	60.3	(6.4)
		NS		***		***		***	
25-29	792	176.4	(7.2)	75.2	(11.3)	17.4	(4.6)	61.8	(7.3)
		NS		***		***		***	
30-34	782	175.8	(6.4)	76.7	(10.5)	21.0	(3.8)	60.3	(6.5)
		NS		NS		NS		NS	
35-39	579	175.7	(6.6)	77.0	(10.6)	21.0	(3.7)	60.5	(6.8)
		NS		NS		***		***	
40-44	269	175.4	(6.7)	78.3	(11.1)	24.6	(4.6)	58.7	(6.4)
		NS		NS		NS		NS	
45-49	142	176.5	(6.3)	80.4	(10.1)	25.5	(4.4)	59.6	(6.0)
		NS		NS		*		NS	
50-59	66	175.3	(7.2)	80.0	(12.7)	27.2	(5.3)	57.7	(6.6)

Key:

NS	Not Significant
*	Significant at the 95% level
**	Significant at the 99% level
***	Significant at the 99.9% level

NB: Significance levels apply to immediately adjacent age groups

Mean Results within Age Groups: Civilians

Table 23

(Standard Deviation in Parenthesis)

Males

n = 1053

Age (Yrs)	n	Height (cm)		Weight (kg)		% Fat		FFM (kg)	
17-19	42	175.4	(6.6)	65.9	(10.4)	14.8	(3.8)	55.8	(6.8)
		NS		*		NS		*	
20-24	145	177.3	(6.1)	69.4	(8.7)	16.0	(3.9)	58.1	(5.8)
		NS		**		**		*	
25-29	170	176.4	(6.6)	72.9	(10.6)	17.5	(4.2)	59.9	(6.9)
		NS		NS		***		**	
30-34	116	175.2	(6.1)	72.7	(10.3)	20.6	(3.8)	57.5	(6.7)
		NS		NS		NS		NS	
35-39	125	175.4	(7.5)	73.7	(10.4)	21.2	(3.8)	57.8	(6.6)
		NS		NS		***		NS	
40-44	105	175.8	(5.9)	74.0	(12.1)	23.4	(4.7)	56.3	(7.0)
		NS		NS		*		NS	
45-49	107	175.1	(6.7)	76.4	(10.6)	24.7	(4.3)	57.2	(6.1)
		NS		NS		***		**	
50-64	243	174.3	(7.0)	75.6	(9.5)	26.8	(4.7)	55.1	(5.5)

Key:
- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% level
- *** Significant at the 99.9% level

N.B. Significance levels apply to immediately adjacent groups

Comparison of Male Forces Sample with Male Civilian Sample

Table 24

(Standard Deviation in Parenthesis)

Age (yrs)	Sample	n	Height (cm)	Weight (cm)	% Fat	FFM (kg)
16	Forces	370	174.7 (6.5)	65.5 (7.8)	13.4 (3.1)	56.5 (5.8)
	Civilians	-	-	-	-	-
17-19	Forces	1,057	175.7 (6.8)	68.2 (9.0)	15.4 (4.0)	57.4 (6.1)
			NS	NS	NS	NS
	Civilians	42	175.4 (6.6)	65.9 (10.4)	14.8 (3.8)	55.8 (6.8)
20-24	Forces	1,274	176.2 (6.9)	72.7 (10.0)	16.6 (4.6)	60.3 (6.3)
			*	***	NS	***
	Civilians	145	177.3 (6.1)	69.4 (8.7)	16.0 (3.9)	58.1 (5.8)
25-29	Forces	792	176.4 (7.2)	75.2 (11.3)	17.4 (4.6)	61.8 (7.3)
			NS	*	NS	**
	Civilians	170	176.4 (6.6)	72.9 (10.6)	17.5 (4.2)	59.9 (6.9)
30-34	Forces	782	175.8 (6.4)	76.7 (10.5)	21.0 (3.8)	60.3 (6.5)
			NS	***	NS	***
	Civilians	116	175.2 (6.1)	72.7 (10.3)	20.6 (3.8)	57.5 (6.7)
35-39	Forces	579	175.7 (6.6)	77.0 (10.6)	21.0 (3.7)	60.5 (6.8)
			NS	**	NS	***
	Civilians	125	175.4 (7.5)	73.7 (10.4)	21.2 (3.8)	57.8 (6.6)
40-44	Forces	269	175.4 (6.7)	78.3 (11.1)	24.6 (4.6)	58.7 (6.4)
			NS	**	*	**
	Civilians	105	175.8 (5.9)	74.0 (12.1)	23.4 (3.8)	56.3 (7.0)
45-49	Forces	142	176.5 (6.3)	80.4 (10.1)	25.5 (4.4)	59.6 (6.0)
			NS	**	*	**
	Civilians	107	175.1 (6.7)	76.4 (10.6)	24.7 (4.3)	57.2 (6.1)
50-59	Forces	66	175.3 (7.2)	80.0 (12.7)	27.1 (5.3)	57.7 (6.6)
			NS	**	NS	**
50-64	Civilians	243	174.3 (7.0)	75.6 (9.5)	26.8 (4.7)	55.1 (5.5)

Key:
- * Significant difference at 95% level between the two sample means
- ** Significant difference at 99% level
- *** Significant difference at 99.9% level
- NS Not Significant

Mean Values for Height, Weight, % Fat and FFM in 12 Geographical Regions: Forces

Table 25

MALES

n = 4723

Region	n	Height (cm)	Weight (kg)	% Fat	FFM
1. Scotland	909	174.1	72.3	18.4	58.6
2. Wales	276	174.9	73.4	18.6	59.4
3. N. Ireland	99	173.8	71.7	18.2	58.2
4. The North	330	175.3	73.4	18.4	59.5
5. Yorkshire/Humberside	357	175.7	72.9	18.1	59.3
6. North West	503	175.4	72.8	18.2	59.1
7. East Midlands	312	175.7	73.4	18.3	59.6
8. West Midlands	318	176.0	73.7	18.3	59.7
9. East Anglia	120	177.7	74.7	17.8	60.9
10. London	240	176.7	74.7	18.1	60.7
11. South East	782	177.2	73.6	18.0	59.9
12. South West	477	176.7	73.1	17.7	59.7
Range of SE		0.22-0.67	0.33-1.02	0.14-0.43	0.21-0.66

All means are adjusted for differences in mean age between the geographical groups

Mean Value for Height, Weight, % Fat and FFM in 3 Geographical Areas: Civilians

Table 26

Area	n	Height(cm)	Weight(kg)	% Fat	FFM	n	Height(cm)	Weight(kg)	% Fat	FFM
		MALES					FEMALES			
A. Scotland	430	175.1	73.0	21.5	57.0	411	161.8	58.0	28.9	41.0
B. England:North	337	175.4	74.0	21.7	57.6	336	162.6	58.9	28.8	41.6
C. England:South	198	176.3	72.6	20.9	56.9	346	162.9	59.7	29.1	41.9

Key: Area B includes the Regions: North of England
Yorks and Humberside
North West England
East Midlands
West Midlands

Area C includes the Regions: London
SouthEast England

All means are adjusted for differences in mean age between the Geographical Areas.

Mean Height in Each Region: OPCS (1981) and Forces Results — Table 27

MALES

	OPCS			FORCES		
	MEAN HEIGHT	MEAN SE	n	MEAN HEIGHT	MEAN SE	n
Scotland	173.0	0.47	436	174.0	0.22	917
North	173.3	0.59	267	175.3	0.37	330
Yorks & Humberside	174.1	0.52	421	175.7	0.35	357
North West	173.1	0.43	554	175.4	0.30	504
East Midlands	174.4	0.42	357	175.7	0.38	312
West Midlands	173.5	0.37	454	176.0	0.38	318
East Anglia	174.8	0.19	114	177.7	0.61	120
London	173.6	0.47	592	176.6	0.43	252
South East	174.7	0.29	878	177.2	0.24	782
South West	175.0	0.50	384	176.6	0.31	477
Wales	172.0	0.63	228	174.9	0.40	276
N Ireland	-	-	-	173.8	0.67	99

Forces n = 4,744

OPCS n = 4,715

Comparison of the Results of OPCS (1981) with our Forces and Civilian Results — Table 28

Average Heights by Social Class and Age - Males

Social Class		16-49 yrs	<20 yrs	20-24 yrs	25-29 yrs	30-34 yrs	35-39 yrs	40-44 yrs	45-49 yrs
I & II	OPCS	-	176.4	178.0	176.9	176.1	175.6	174.9	174.5
	FORCES	177.3 (757)	177.8 (26)	178.0 (140)	177.9 (173)	177.1 (170)	176.7 (132)	175.7 (71)	177.8 (45)
	CIVILIANS	176.3 (373)	174.6 (8)	177.3 (42)	177.1 (95)	175.6 (61)	175.2 (68)	176.5 (46)	176.6 (53)
III (non-man)	OPCS	-	174.9	178.3	176.1	176.2	174.2	175.2	176.3
	FORCES	176.2 (413)	176.1 (88)	176.1 (76)	177.8 (50)	175.6 (75)	175.7 (69)	177.1 (37)	175.6 (18)
	CIVILIANS	176.1 (320)	176.6 (20)	177.6 (74)	176.3 (62)	175.1 (44)	175.5 (45)	175.1 (42)	175.3 (33)
III (manual)	OPCS	-	174.7	175.1	174.6	174.1	174.5	173.1	172.9
	FORCES	175.7 (3054)	175.4 (847)	176.3 (827)	175.8 (460)	175.4 (430)	175.1 (308)	174.7 (125)	176.4 (57)
IV & V	OPCS	-	173.0	174.9	173.9	173.7	173.3	171.6	170.3
	FORCES	174.9 (822)	174.0 (286)	175.1 (198)	175.8 (108)	175.6 (104)	175.9 (68)	175.0 (36)	175.2 (22)

No in brackets = n

Total FORCES = 5046

OPCS = 3484

CIVILIAN = 693

Comparison of the Forces and Civilian Results

Table 29 (a)

Mean Height in Social Class Groups: Males

Social Class		16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-59
I & II	F	-	177.8 (5.2)	178.0 (6.9)	177.9 (6.8)	177.1 (6.1)	176.7 (6.5)	175.7 (6.7)	177.8 (5.6)	176.4 (7.3)
	C	-	174.6 (8.6)	177.3 (6.2)	177.1 (5.3)	175.6 (4.7)	175.2 (8.0)	176.5 (5.2)	176.6 (6.3)	175.3 (6.9)
III (nm)	F	174.7 (5.9)	176.5 (7.6)	176.1 (6.6)	177.8 (6.5)	175.6 (6.6)	175.7 (6.8)	177.1 (7.1)	175.6 (5.8)	174.9 (5.1)
	C	-	176.6 (6.1)	177.6 (6.1)	176.3 (7.6)	175.1 (7.4)	175.5 (6.9)	175.1 (6.6)	175.3 (6.9)	174.0 (6.9)
III (m) & IV	F	174.3 (6.3)	175.7 (6.4)	176.2 (6.8)	175.8 (7.2)	175.3 (6.4)	175.3 (6.5)	174.8 (6.6)	175.9 (6.8)	174.6 (7.8)
	C	-	173.8 (5.8)	176.5 (6.4)	173.4 (7.9)	173.9 (7.1)	175.1 (6.8)	176.1 (6.6)	170.9 (6.6)	172.0 (6.5)
V	F	170.1 (7.9)	173.7 (7.1)	174.9 (6.7)	176.2 (8.1)	177.4 (6.1)	176.3 (6.3)	177.2 (4.7)	-	-
	C	-	174.8 (7.6)	175.1 (7.1)	-	-	-	174.9 (1.6)	171.3 (4.5)	171.4 (8.9)

Mean Weight in Social Class Groups: Males

Table 29(b)

Social Class		16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-59	Total
I & II	F	-	67.9 (8.6)	74.1 (9.3)	75.6 (10.1)	76.7 (9.6)	76.3 (9.8)	77.8 (11.2)	80.2 (7.8)	80.5 (10.4)	781
	C	-	61.1 (8.0)	67.9 (8.2)	73.3 (11.3)	73.0 (9.8)	72.6 (9.7)	75.6 (14.8)	77.0 (11.0)	76.4 (9.7)	486
III(nm)	F	64.7 (6.3)	68.0 (8.4)	72.2 (9.3)	76.3 (9.2)	76.4 (12.6)	76.9 (10.1)	79.1 (10.6)	78.5 (10.1)	80.2 (10.0)	425
	C	-	66.2 (8.6)	69.2 (7.5)	71.8 (9.1)	71.7 (11.2)	74.4 (11.1)	70.7 (8.7)	75.5 (9.8)	74.7 (8.9)	414
III (m) & IV	F	64.6 (7.5)	68.2 (9.1)	72.6 (10.1)	75.0 (11.8)	76.4 (10.6)	77.4 (11.1)	78.2 (11.5)	80.8 (11.1)	79.4 (15.5)	3465
	C	-	67.7 (9.3)	72.0 (9.8)	76.5 (11.9)	74.8 (9.9)	76.7 (12.8)	78.0 (10.2)	77.2 (12.0)	77.0 (9.3)	118
V	F	61.6 (7.9)	68.7 (9.7)	73.2 (9.6)	76.4 (12.1)	80.8 (8.3)	74.1 (8.2)	83.4 (6.1)	-	-	425
	C	-	68.9 (18.4)	77.9 (19.9)	-	-	-	76.3 (7.7)	71.5 (2.7)	72.9 (11.5)	31

Key: No in bracket = SD
Only group with n ≥ 3 are shown
F = Forces
C = Civilians

Groups showing a significant difference between them are marked:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

Comparison of the Forces and Civilian Results

Table 29(c)

Mean % Fat in Social Class Groups: Males

Social Class		16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-59	Total
I & II	F	-	14.8 (3.8)	15.4 (3.8)	16.8 (4.3)	20.6 (3.6)	20.8 (3.6)	24.2 (4.6)	25.4 (5.1)	26.3 (5.2)	781
	C	-	12.8 (2.4)	16.0 (3.0)	17.0 (4.3)	20.6 (3.7)	21.1 (3.7)	23.5 (5.4)	24.5 (4.2)	26.7 (4.6)	486
III (nm)	F	14.0 (3.1)	15.6 (4.2)	*16.7 (4.9)	*17.0 (4.0)	21.4 (3.5)	20.9 (3.5)	24.5 (4.4)	25.2 (4.7)	28.9 (3.4)	425
	C	-	*15.1 (3.6)	***16.1 (3.3)	17.9 (4.2)	20.4 (4.0)	21.3 (3.7)	23.5 (3.9)	25.1 (4.2)	27.0 (4.9)	414
III (m) & IV	F	13.5 (3.2)	15.6 (4.1)	16.8 (4.7)	17.6 (4.7)	21.1 (4.0)	21.2 (3.8)	24.8 (4.7)	25.7 (3.7)	27.3 (6.0)	3465
	C	-	14.9 (4.6)	15.9 (4.8)	19.2 (3.3)	20.7 (3.3)	21.1 (4.5)	22.7 (4.8)	24.6 (5.0)	27.3 (4.0)	118
V	F	12.9 (2.6)	15.7 (4.0)	***16.7 (4.3)	17.1 (4.6)	21.3 (2.7)	19.9 (3.1)	24.7 (4.0)	-	-	425
	C	-	16.4 (4.9)	17.6 (8.2)	-	-	-	26.2 (2.8)	24.3 (5.3)	25.5 (6.5)	31

Mean FFM in Social Class Groups: Males

Table 29(d)

Social Class		16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-59
I & II	F	-	57.6 (5.4)	62.5 (6.4) ***	62.6 (6.8) *	60.7 (6.1) **	60.3 (6.4) ***	58.6 (6.6)	59.6 (4.6)	59.0 (5.3)
	C	-	53.2 (6.6)	56.8 (5.4)	60.5 (7.1)	57.7 (6.3)	57.0 (6.3)	57.2 (7.7)	57.8 (6.3)	55.7 (5.6)
III (nm)	F	55.6 (5.0)	57.6 (5.9)	59.8 (5.8) ** *	63.1 (6.4) ***	59.7 (8.0) ** *	60.6 (6.5)	59.5 (6.4) ***	58.3 (5.2)	56.9 (6.6)
	C	-	56.0 (5.7)	57.9 (5.3)	58.8 (6.2)	56.8 (7.4)	58.5 (7.1)	*54.0 (5.9)	56.3 (5.6)	54.3 (5.2)
III (m) & IV	F	55.8 (5.6)	57.3 (6.0)	60.0 (6.3)	*61.2 (7.4)	60.0 (6.5)	60.6 (7.0)	58.5 (6.5)	59.8 (6.8)	57.0 (7.6)
	C	- *	57.3 (6.2)	***60.2 *(6.5)	61.6 (8.5)***	59.1 ***(6.6)	60.0 (6.9)	60.1 **(6.5)	57.8 (6.7)	55.7 (5.8)
V	F	53.5 (6.2)	57.7 (6.7)	60.7 (6.0)	*63.0 (8.3)	63.5 (5.6)	59.3 (5.2)	*62.7 (3.9) **	-	- *
	C	-	56.8 (11.1)	63.1 (9.3)	-	-	-	56.1 (3.2)	54.2 (4.2)	53.7 (5.5)

Key:

No in bracket = SD
Only group with n > 3 are shown
F = Forces
C = Civilians

Groups showing a significant difference between them are marked:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

Mean Results within Age Groups: Forces

(Standard Deviation in Parenthesis)

Table 30

FEMALES

n = 1086

Age (Yrs)	n	Height (cm)		Weight (kg)		% Fat		FFM (kg)	
17-19	405	163.1	(6.1)	60.5	(8.1)	28.0	(4.0)	43.4	(4.5)
		*		NS		NS		NS	
20-24	488	164.1	(6.9)	61.5	(8.8)	28.1	(4.6)	43.9	(4.7)
		NS		NS		NS		NS	
25-29	118	164.1	(5.1)	61.0	(9.7)	27.1	(5.2)	44.0	(5.1)
		***		NS		**		***	
30-34	38	160.1	(6.3)	58.7	(7.5)	29.7	(3.6)	41.1	(4.0)
		NS		NS		NS		NS	
35-39	14	164.3	(6.2)	64.5	(8.3)	30.6	(3.8)	44.5	(4.2)
		NS		NS		NS		NS	
40-44	13	162.4	(6.2)	67.7	(14.1)	34.0	(5.9)	44.1	(6.5)
		NS		NS		NS		NS	
45-49	6	163.3	(11.9)	60.9	(7.1)	31.1	(3.4)	41.9	(4.5)
		NS		NS		NS		NS	
50-59	4	162.1	(3.9)	66.8	(8.6)	35.7	(3.8)	42.7	(5.2)

Key:
- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% Level
- *** Significant at the 99.9% level

NB. Significancelevels apply to immediately adjacent groups

Mean Results within Age Groups: Civilians

(Standard Deviation in Parenthesis)

Table 31

Females

n = 1169

Age(Yrs)	n	Height (cm)		Weight (kg)		% Fat		FFM (kg)	
16	6	163.5	(2.1)	57.7	(8.2)	25.0	(4.9)	42.9	(3.6)
		NS		NS		NS		NS	
17-19	136	162.2	(5.6)	55.5	(7.1)	25.2	(3.9)	41.3	(3.9)
		*		*		**		***	
20-24	338	163.4	(5.9)	57.3	(7.6)	26.4	(4.4)	42.0	(4.0)
		NS		NS		NS		NS	
25-29	171	162.6	(5.8)	56.7	(7.4)	26.2	(4.0)	41.7	(4.5)
		NS		NS		***		NS	
30-34	67	162.4	(6.6)	57.6	(8.9)	28.3	(4.0)	41.0	(4.5)
		NS		NS		NS		NS	
35-39	81	162.0	(6.9)	59.7	(10.3)	29.1	(3.7)	42.1	(5.8)
		NS		NS		***		NS	
40-44	84	162.5	(6.9)	61.6	(10.0)	32.2	(4.0)	41.6	(5.8)
		NS		NS		NS		NS	
45-49	87	162.4	(6.1)	62.9	(9.6)	33.0	(3.8)	41.9	(4.9)
		*		NS		***		**	
50-64	197	160.7	(6.3)	63.0	(10.0)	35.7	(4.0)	40.2	(4.9)

Key:

NS	Not Significant
*	Significant at the 95% level
**	Significant at the 99% level
***	Significant at the 99.9 % level

N.B. Significancelevels apply to immediately adjacent groups

Comparison of Female Forces Sample with Female Civilian Sample — Table 32

(Standard Deviation in Parenthesis)

Age (yrs)	Sample	n	Height (cm)	Weight (kg)	% Fat	FFM (kg)
16	Forces	-	-	-	-	-
	Civilians	6	163.5 (2.1)	57.7 (8.2)	25.0 (4.9)	42.9 (3.6)
17-19	Forces	405	163.1 (6.1)	60.5 (8.1)	28.0 (4.0)	43.4 (4.5)
			NS	***	***	***
	Civilians	136	162.2 (5.6)	55.5 (7.1)	25.2 (3.9)	41.3 (3.9)
20-24	Forces	488	164.1 (6.9)	61.5 (8.8)	28.1 (4.6)	43.9 (4.7)
			NS	***	***	***
	Civilians	339	163.4 (5.9)	57.3 (7.6)	26.4 (4.4)	42.0 (4.0)
25-29	Forces	118	164.1 (5.1)	61.0 (9.7)	27.1 (5.2)	44.0 (5.1)
			**	***	NS	***
	Civilians	171	162.6 (5.8)	56.7 (7.4)	26.2 (4.0)	41.7 (4.5)
30-34	Forces	38	160.1 (6.3)	58.7 (7.5)	29.7 (3.6)	41.1 (4.0)
			NS	NS	NS	NS
	Civilians	67	162.4 (6.6)	57.6 (8.9)	28.3 (4.0)	41.0 (4.5)
35-39	Forces	14	164.3 (6.2)	64.5 (8.3)	30.6 (3.8)	44.5 (4.2)
			NS	NS	NS	NS
	Civilians	81	162.0 (6.9)	59.7 (10.3)	29.1 (3.7)	42.1 (5.8)
40-44	Forces	13	162.4 (6.2)	67.7 (14.1)	34.0 (5.9)	44.1 (6.5)
			NS	NS	NS	NS
	Civilians	86	162.5 (6.9)	61.6 (10.0)	32.2 (4.0)	41.6 (5.8)
45-49	Forces	6	163.3 (11.8)	60.9 (7.1)	31.1 (3.4)	41.9 (4.5)
			NS	NS	NS	NS
	Civilians	87	162.3 (6.1)	62.9 (9.6)	33.0 (3.8)	41.9 (4.9)
50-64	Forces	4	162.1 (3.9)	66.8 (8.6)	35.7 (3.2)	42.7 (3.2)
			NS	NS	NS	NS
	Civilians	197	160.7 (6.3)	63.0 (10.0)	35.7 (4.0)	40.2 (4.9)

Key:

- * Significant difference at 95% level between the two sample means
- ** Significant difference at 99% level
- *** Significant difference at 99.9% level
- NS Not significant

Mean Values for Height, Weight, % Fat and FFM in 12 Geographical Regions: Forces

Table 33

FEMALES

n = 934

Region	n	Height (cm)	Weight (kg)	% Fat	FFM
1. Scotland	111	161.5	59.5	28.2	42.5
2. Wales	56	161.9	61.6	29.4	43.3
3. N Ireland	15	163.6	57.3	25.9	42.3
4. The North	56	163.0	61.7	28.0	44.2
5. Yorkshire/Humberside	108	163.2	61.2	28.5	43.5
6. North West	113	162.1	60.5	28.2	43.2
7. East Midlands	74	165.1	60.5	27.4	43.7
8. West Midlands	88	162.7	59.7	28.2	42.6
9. East Anglia	18	162.5	61.9	27.6	44.5
10. London	27	164.2	63.7	29.6	44.5
11. South East	147	165.5	62.7	27.9	44.6
12. South West	103	163.9	61.1	28.1	43.7
Range of SE		0.55-1.70	0.81-2.21	0.44-1.20	0.42-1.16

All means are adjusted for differences in mean age between the geographical groups

Table 34

Mean Height in Each Region: OPCS (1981) and Forces Results

FEMALES

	OPCS			FORCES		
	MEAN HEIGHT	MEAN SE	n	MEAN HEIGHT	MEAN SE	n
Scotland	160.0	0.37	492	161.5	0.65	113
North	160.0	0.24	294	163.0	0.88	56
Yorks & Humberside	160.9	0.43	453	163.2	0.63	108
North West	160.2	0.3	621	162.2	0.62	113
East Midlands	161.0	0.25	381	165.1	0.77	74
West Midlands	160.6	0.23	488	162.6	0.70	88
East Anglia	160.9	0.36	147	162.4	1.56	18
London	161.0	0.40	673	164.2	1.27	27
South East	161.9	0.31	950	165.5	0.54	147
South West	161.8	0.38	415	163.9	0.65	103
Wales	159.9	0.40	256	161.9	0.88	56
N Ireland	-	-	-	163.6	1.7	15

Forces n = 918

OPCS n = 5,170

Comparison of the Results of OPCS 1981 with Forces and Civilian Samples — Table 35

Average Height by Social Class and Age - Females

Social Class		17-49 yrs	<20 yrs	20-24 yrs	25-29 yrs	30-34 yrs	35-39 yrs	40-44 yrs	45-49 yrs
I & II	OPCS	-	163.4	162.8	163.2	163.4	161.5	162.1	162.9
	FORCES	163.4 (339)	162.5 (99)	164.2 (158)	163.0 (48)	159.7 (19)	164.9 (4)	165.4 (6)	166.5 (5)
	CIVILIANS	163.4 (167)	165.3 (11)	163.9 (50)	162.3 (42)	162.0 (16)	163.4 (22)	164.3 (13)	164.7 (13)
III (non man)	OPCS	-	163.1	163.5	163.0	162.2	162.3	162.5	160.7
	FORCES	163.8 (274)	163.8 (71)	164.3 (142)	163.5 (37)	160.2 (10)	165.4 (9)	157.8 (4)	147.5 (1)
	CIVILIANS	162.6 (768)	161.9 (124)	163.4 (276)	162.6 (128)	162.4 (48)	161.3 (55)	162.4 (68)	162.1 (69)
III (manual)	OPCS	-	160.9	160.1	161.0	161.9	160.9	159.9	160.2
	FORCES	164.1 (171)	163.1 (85)	165.1 (68)	165.5 (15)	160.2 (2)	-	165.6 (1)	-
IV & V	OPCS	-	160.1	161.5	160.7	160.1	160.2	160.0	159.0
	FORCES	163.5 (210)	164.0 (82)	163.0 (104)	167.0 (15)	161.2 (5)	152.4 (1)	160.9 (2)	156.2 (1)

TOTAL FORCES = 994
OPCS = 3728
CIVILIANS = 935

Comparison of the Forces and Civilian Results

Table 36(a)

Mean Height in Social Class Groups: Females

Social Class		16	17–19	20–24	25–29	30–34	35–39	40–44	45–49	50–59
I & II	F	–	162.5 (6.1)	164.2 (6.4)	163.0 (7.5)	159.7 (5.8)	164.9 (5.3)	165.4 (6.7)	166.5 (10.1)	163.6 (2.4)
	C	–	165.3 (6.1)	163.9 (4.9)	162.3 (6.3)	162.0 (6.4)	163.4 (7.6)	* 164.3 (7.0)	164.7 (7.3)	162.5 (6.9)
III (m)	F	–	163.8 (6.5)	164.3 (7.3)	163.5 (6.2)	160.2 (5.6)	165.4 (5.9)	157.8 (4.9)	–	–
	C	–	* 161.9 (5.5)	163.4 (6.1)	* 162.6 (5.5)	162.4 (6.4)	161.3 (6.6)	162.4 (7.1)	162.1 (6.0)	160.4 (5.9)
III (m) & IV	F	–	163.5 (6.3)	163.9 (7.2)	166.3 (6.4)	160.9 (3.2)	–	162.5 (3.1)	–	–
	C	–	–	164.6 (4.9)	–	–	–	–	–	–
V	F	–	–	–	–	–	–	–	–	–
	C	–	164.0 (8.0)	159.9 (5.3)	–	–	161.5 (8.3)	160.4 (3.7)	159.7 (1.8)	158.1 (10.5)

Mean Weight in Social Class Groups: Females

Table 36(b)

Social Class		16	17–19	20–24	25–29	30–34	35–39	40–44	45–49	50–59
I & II	F	–	61.8 (7.1)	62.2 (9.2)	58.7 (9.1)	57.6 (8.4)	65.0 (10)	63.7 (10.3)	63.2 (4.9)	64.8 (8.5)
	C	–	60.8 (7.5)	*** 56.7 (8.5)	56.4 (8.0)	55.9 (7.4)	61.7 (10.8)	65.4 (14)	62.6 (9.5)	60.8 (9.3)
III (nm)	F	–	61.8 (8.9)	60.6 (8.0)	61.2 (7.6)	60.0 (7.9)	64.4 (8.7)	72.5 (20.5)	–	–
	C	–	* *** 54.8 (7.0)	*** 57.3 (7.4) *	** 56.7 (7.2)	57.1 (7.8)	* 58.5 (9.9)	61.4 (9.2)	62.6 (9.2)	63.5 (9.6)
III (m) & IV	F	–	60.7 (8.0)	61.5 (9.0)	63.9 (12.0)	59.4 (5.3)	–	69.5 (13.0)	–	–
	C	–	–	62.5 (8.0)	–	–	–	–	–	–
V	F	–	–	–	–	–	–	–	–	–
	C	–	60.9 (14.0)	58.3 (8.4)	–	–	65.1 (15.2)	55.4 (4.6)	66.8 (15.1)	63.3 (20.4)

Key: No in brackets = SD
Only groups with n ≥ 3 are shown
F = Forces
C = Civilians

Groups showing a significant difference between them are marked:
$p < 0.05$ *
$p < 0.01$ **

Comparison of Forces and Civilian Results

Table 36(c)

Mean % Fat in Social Class Groups: Females

Social Class		16	17–19	20–24	25–29	30–34	35–39	40–44	45–49	50–59	Total
I & II	F	–	29.0 (4.0)	28.6 (4.7)	26.0 (5.0)	29.2 (4.1)	31.3 (5.4)	32.3 (5.4)	31.6 (3.6)	35.0 (3.9)	343
			*	***							
	C	–	26.5 (3.6)	25.9 (4.4)	25.7 (4.3)	27.8 (4.5)	29.1 (4.0)	30.8 (5.1)	32.2 (3.2)	34.4 (4.5)	202
III (nm)	F	–	28.7 (4.0) *	27.4 (4.5)	27.2 (5.8)	29.6 (3.1)	29.8 (3.0)	35.1 (7.6)	–	–	273
			***	*	*						
	C	–	* 24.9 (3.9)	26.4 (4.4)	26.3 (3.9)	28.0 (3.5)	29.0 (3.5)	32.6 (3.7)	33.0 (3.8)	36.1 (3.7)	924
III (m) &IV	F	–	27.9 (3.8)	28.2 (4.5)	28.5 (4.7)	30.8 (3.3)	–	36.2 (5.4)	–	–	381
	C	–	–	26.5 (5.2)	–	–	–	–	–	–	5
V	F	–	–	–	–	–	–	–	–	–	–
	C	–	29.1 (5.6)	27.9	–	–	30.5 (5.5)	29.9 (3.9)	34.1 (5.4)	34.6 (5.9)	29

Mean FFM in Social Class Groups: Females

Table 36(d)

Social Class		16	17–19	20–24	25–29	30–34	35–39	40–44	45–49	50–59
I & II	F	–	43.7 (3.8)	44.1 (4.8)	43.1 (4.8)	40.5 (4.1)	44.3 (3.7)	42.9 (6.6)	43.2 (3.5)	41.9 (3.0)
				***						
	C	–	44.6 (4.0)	41.7 (4.0)	41.7 (5.3)	40.1 (3.2)	43.3 (6.0)	45.0 (9.5)	42.3 (6.0)	39.6 (4.5)
III (nm)	F	–	43.9 (5.4)	43.7 (4.5)	44.3 (4.1)	42.1 (4.7)	45.0 (4.7)	45.9 (8.5)	–	–
			** ***	***	*		*			
	C	–	41.0 (3.8)	42.0 (3.9)	41.6 (4.2)	40.9 (4.2)	41.3 (5.5)	41.2 (4.8)	41.7 (4.6)	40.3 (4.8)
III (m) & IV	F	–	43.5 (4.5) *	43.9 (4.8)	45.3 (6.5)	41.0 (2.6)	–	43.9 (5.3)	–	–
				**						
	C	–	–	45.6 (2.8)	–	–	–	–	–	–
V	F	–	–	–	–	–	–	–	–	–
	C	–	42.8 (6.1)	41.8 (4.5)	–	–	44.8 (8.1)	38.7 (1.6)	43.4 (6.3)	40.6 (9.2)

Key: No in brackets = SD
Only groups with n > 3 are shown
F = Forces
C = Civilians

Groups showing a significant difference between them are marked:
$p < 0.05$ *
$p < 0.01$ **
$p < 0.001$ ***

Height Distribution of the OPCS (1981) and Forces Samples

Table 37

MALES

Height (cm)	OPCS %	Forces%	Forces (-) %
≤160	2	0.7	0.8
160.1-162.5	2	1.5	1.2
162.6-165.0	5	3	3
165.1-167.5	8	5.5	6.0
167.6-170.0	12	8	8
170.1-172.5	13	12.5	13
172.6-175.0	14	14	14
175.1-177.5	14	15	14.5
177.6-180.0	12	12	12
180.1-182.5	7	11	11
182.6-185.0	5	7.5	7.5
185.1-187.5	3	4	4
187. -190.0	1	3	3
190.1-193.5	1	2	2
≥193.5	0	0.3	0.4
Mean	173.8	175.9	175.
Median	173.8	175.5	175.5

FEMALES

Height (cm)	OPCS %	Forces %
≤150	0	1.5
150.1-152.5	4	2.5
152.6-155.0	5	5
155.1-157.5	8	9.5
157.6-160.0	13	13
160.1-162.5	16	14
162.6-165.0	15	14
165.1-167.5	15	12.5
167.6-170.0	10	12
170.1-172.5	7	7
172.6-175.0	4	2
175.1-177.5	2	5
≥177.5	1	2
Mean	160.7	163.6
Median	160.8	163.3

Forces (-): Forces sample minus the Footguards and Household Cavalry

Comparison of the Results of the OPCS (1981) Survey and Our Forces Results — Table 38(a)

Average Weights in Height and Age Groups: Males

Age (yrs)	Height (cm)	<165	165.1 - 170	170.1 - 175	175.1-180	>180
16-19	OPCS	59.5 (108)		63.5 (131)	68.2 (147)	71.4 (87)
16-19	FORCES	60.1 (289)		65.3 (402)	68.9 (387)	74.6 (349)
16-19	CIVILIANS	56.3 (11)		68.9 (5)	66.1 (13)	72.6 (18)
20-29	OPCS	60.9 (73)	67.8 (160)	69.9 (265)	74.4 (280)	79.9 (277)
"	FORCES	61.8 (109)	66.9 (257)	70.6 (513)	74.5 (548)	80.0 (639)
"	CIVILIANS	60.9 (10)	64.1 (28)	69.3 (81)	71.4 (108)	74.6 (88)
30-39	OPCS	64.0 (72)	69.7 (162)	74.5 (243)	77.2 (305)	81.8 (187)
"	FORCES	68.1 (58)	70.1 (187)	78.1 (369)	78.1 (369)	83.5 (356)
"	CIVILIANS	62.8 (13)	68.7 (35)	70.1 (71)	74.0 (62)	81.0 (60)
40-49	OPCS	66.8 (79)	72.6 (168)	79.8 (247)	79.8 (200)	85.4 (135)
"	FORCES	67.9 (20)	72.3 (52)	75.9 (109)	78.5 (119)	87.5 (111)
"	CIVILIANS	70.4 (9)	68.0 (31)	71.5 (61)	77.6 (63)	81.8 (50)
50-64	OPCS	65.2 (187)	71.9 (311)	75.6 (388)	79.1 (231)	85.4 (105)
50-59	FORCES	64.5 (4)	73.6 (11)	76.0 (15)	83.0 (21)	88.5 (15)
50-64	CIVILIANS	66.1 (18)	71.5 (44)	74.1(67)	77.3 (61)	82.4 (53)

(For ages 16-19 the values cover the combined <165 and 165.1 - 170 groups.)

No. in brackets = n

FORCES: Mean SD within 1 group = 10 kg

CIVILIAN: Mean SD within 1 group = 8 kg

Table 38(b)

Comparison of the Results of the Forces and Civilian Samples

FORCES: n = 5331

Average % Fat in Height and Age Groups: Males

CIVILIAN: n = 1053

Age		Height 155-159.9	160-164.9	165-169.9	170-174.9	175-179.9	180-184.9	185-189.9
17-19	F	14.9	14.1	14.9	15.4	15.6	15.8	15.5
				*	NS	NS	NS	
	C	-	(12.0)	13.1	16.4	14.9	15.6	(16.6)
20-24	F	17.4	15.7	16.6	16.6	16.8	16.4	16.8
				NS	NS	NS	NS	NS
	C	-	(17.0)	16.1	16.1	15.9	16.1	16.3
25-29	F	13.5	16.5	16.7	17.1	17.9	17.7	17.4
			NS	NS	NS	NS	NS	NS
	C	(19.0)	18.5	17.5	18.2	16.9	17.0	18.1
30-34	F	23.7	20.3	21.1	20.7	21.0	21.3	21.3
				NS	NS	NS	*	NS
	C	(20.6)	(23.3)	20.4	19.3	21.7	19.3	21.0
35-39	F	26.3	21.8	20.7	21.1	21.0	20.6	21.8
			NS	*	NS	*	NS	NS
	C	(12.7)	20.5	22.6	21.5	19.3	21.3	21.9
40-44	F	20.6	23.5	23.2	24.8	24.5	25.1	26.2
				NS	*	NS	NS	NS
	C	(23.9)	(27.9)	22.9	22.8	24.3	22.7	25.6
45-49	F	22.1	24.0	28.4	25.6	24.7	25.0	26.8
			NS	**	NS	NS	NS	**
	C	(25.5)	27.3	24.1	24.3	24.8	25.8	22.2

Key: F = Forces Mean
C = Civilian mean
( ) n in this group ≤ 3

* Difference between the means significant at 95% level
** Difference between the means significant at 99% level
*** Difference between the means significant at 99.9% level
NS No significant difference between the means

Comparison of the Results of the Forces and Civilian Samples — Table 38(c)

Average FFM in Height and Age Groups: Males

Forces n = 5331 — Civilians n = 1053

Age		Height 155-159.9	160-164.9	165-169.9	170-174.9	175-179.9	180-184.9	185-189.9
17-19	F	47.9	49.0	52.9	55.3	58.2	61.8	64.8
				**	NS	**	NS	
	C	-	(46.7)	50.0	57.1	56.0	59.7	(67.1)
20-24	F	49.0	52.0	55.3	58.2	60.7	64.1	66.9
				NS	**	***	**	**
	C	-	(47.9)	52.0	55.9	57.6	61.6	61.9
25-29	F	47.1	52.8	55.8	59.1	62.4	65.4	69.2
			*	NS	NS	*	NS	NS
	C	(50.7)	49.5	53.9	57.9	61.0	63.0	66.5
30-34	F	50.8	52.8	55.6	57.8	61.4	64.2	68.1
				NS	**	***	NS	NS
	C	(43.9)	(50.8)	53.1	54.8	58.6	62.4	66.3
35-39	F	54.5	53.6	54.7	58.8	61.5	63.9	69.4
			NS	NS	***	**	NS	*
	C	(44.1)	51.7	54.0	55.8	58.0	63.0	65.1
40-44	F	48.7	51.3	54.0	56.2	58.7	64.9	66.5
				*	**	NS	NS	NS
	C	(40.7)	(49.5)	49.9	53.3	57.3	61.7	66.5
45-49	F	47.0	54.8	56.2	57.4	59.4	61.6	66.4
			NS	NS	NS	NS	NS	*
	C	(45.9)	56.1	52.9	55.3	59.6	60.9	61.9

Key: F = Forces Mean
C = Civilian Mean
( ): in this group n ≤3

* Difference between the means significant at 95% level
** Difference between the means significant at 99% level
*** Difference between the means significant at 99.9% level
NS No significant difference between the means

Comparison of the Results of the OPCS (1981) Survey and our Forces Results — Table 39(a)

Average Weights in Height and Age Groups: Females

Age (yrs)	Height (cm)	≤155	155.1-160.0	160.1-165.0	165.1-170.0	>170
16-19	OPCS	-	51.1 (109)	56.3 (179)	59.7 (129)	63.2 (79)
17-19	FORCES	-	56.0 (133)	59.6 (114)	63.6 (99)	67.4 (59)
16-19	CIVILIANS	-	52.1 (32)	54.2 (56)	58.9 (30)	64.5 (14)
20-29	OPCS	53.3 (80)	56.1 (198)	58.8 (334)	61.2 (307)	64.4 (179)
"	FORCES	52.9 (53)	56.5 (113)	60.3 (169)	63.5 (158)	68.2 (112)
"	CIVILIANS	51.6 (29)	53.7 (115)	57.2 (169)	59.1 (136)	63.2 (60)
30-39	OPCS	54.7 (64)	57.2 (202)	61.2 (331)	63.9 (287)	67.0 (169)
"	FORCES	56.3 (5)	55.9 (18)	61.1 (16)	65.4 (8)	69.9 (6)
"	CIVILIANS	50.5 (20)	54.9 (37)	58.8 (47)	63.4 (25)	68.2 (19)
40-49	OPCS	57.4 (66)	60.0 (197)	62.7 (276)	67.3 (229)	70.3 (123)
"	FORCES	51.6 (4)	80.1 (3)	68.6 (5)	63.2 (4)	71.6 (1)
"	CIVILIANS	56.4 (17)	58.9 (42)	61.6 (57)	64.8 (34)	70.1 (23)
50-64	OPCS	58.0 (168)	62.0 (375)	65.3 (437)	67.8 (259)	71.1 (134)
50-59	FORCES	-	74.8 (1)	62.2 (3)	72.8 (1)	-
50-64	CIVILIANS	57.2 (36)	59.7 (55)	64.8 (62)	66.9 (24)	71.9 (20)

The number in brackets = n

FORCES: Mean SD within 1 group = 8.1 kg

CIVILIANS: Mean SD within 1 group = 7.2 kg

Comparison of the Results of the Forces and Civilian Samples

Table 39(b)

Average % Fat in Height and Age Groups: Females

Forces n = 1083

Civilian n = 1169

Age		Height 150-154.9	155-159.9	160-164.9	165-169.9	170-174.9	175-179.9
17-19	F	27.6	28.0	28.0	28.3	27.9	28.7
		NS	***	***	**	NS	
	C	26.7	24.9	24.5	25.6	26.3	-
20-24	F	28.1	28.1	28.5	27.8	28.3	27.2
		NS	**	***	***	NS	NS
	C	28.0	26.3	26.5	25.6	26.4	30.3
25-29	F	26.7	25.7	27.1	27.3	27.5	29.5
		NS	NS	NS	NS	NS	
	C	28.6	26.0	26.1	26.3	26.4	(26.4)
30-34	F	(28.7)	28.8	30.8	30.7	(31.3)	(29.1)
			NS	NS	NS		
	C	27.5	26.9	28.9	29.4	25.1	(29.2)
35-39	F	(35.2)	(27.4)	30.3	(30.2)	(32.3)	-
				NS			
	C	28.8	29.3	28.1	29.3	28.2	(33.6)

Key:
F = Forces Mean
C = Civilian Mean
( ) in this group n≤3

* Difference between the means significant at 95% level
** Difference between the means significant at 99% level
*** Difference between the means significant at 99.9% level
NS No significant difference between the means

Comparison of the Results of the Forces and Civilian Samples — Table 39(c)

Average FFM in Height and Age Groups: Females

Forces n = 1083 — Civilians n = 1169

Age		Height 150-154.9	155.159.9	160-164.9	165.169.9	170-174.9	175-179.9
17-19	F	38.9	40.8	42.7	45.3	47.5	50.4
		NS	**	***	*	NS	
	C	37.9	39.3	40.5	43.6	47.2	-
20-24	F	39.2	40.4	43.1	45.8	47.7	48.9
		NS	*	NS	***	**	NS
	C	38.1	39.4	41.4	43.5	44.7	49.9
25-29	F	38.1	41.5	42.9	45.2	47.7	52.5
		NS	NS	*	NS	**	
	C	36.4	39.5	41.3	43.9	44.7	(47.1)
30-34	F	(40.2)	39.3	41.0	46.2	(49.2)	(46.8)
			NS	NS	NS		
	C	37.5	37.8	41.1	44.1	45.7	(48.0)
35-39	F	(40.7)	(43.0)	44.1	(42.8)	(48.7)	-
				NS			
	C	35.5	40.3	42.5	44.8	45.4	(54.5)

Key: F = Forces Mean
C = Civilian Mean
( ): in this group n≤3

* Difference between the means significant at 95% level
** Difference between the means significant at 99% level
*** Difference between the means significant at 99.9% level
NS No significant difference between the means

Mean Results for Bone Diameters within Age Groups: Forces

(Standard Deviation in Parenthesis)

Table 40(a)

MALES

n = 5331

Age (Yrs)	n	Ulnar (cm)		Tibial (cm)		Biacromial (mm)		Bi-iliac (mm)	
16	370	5.8	(0.3)	9.9	(0.4)	39.1	(1.7)	27.3	(1.5)
		NS		***		***		*	
17-19	1057	5.8	(0.3)	9.8	(0.5)	39.7	(1.9)	27.5	(1.5)
		NS		NS		***		***	
20-24	1274	5.8	(0.3)	9.8	(0.5)	40.3	(1.9)	28.0	(1.6)
		NS		***		NS		***	
25-29	792	5.8	(0.3)	9.9	(0.5)	40.5	(1.9)	28.4	(1.7)
		***		NS		NS		**	
30-34	782	5.9	(0.3)	9.9	(0.4)	40.4	(1.9)	28.7	(2.8)
		NS		NS		NS		NS	
35-39	579	5.9	(0.3)	9.9	(0.5)	40.4	(1.9)	28.9	(1.7)
		***		NS		NS		NS	
40-44	269	6.0	(0.3)	9.9	(0.5)	40.6	(1.9)	29.0	(1.5)
		NS		NS		NS		***	
45-49	142	6.0	(0.3)	9.9	(0.4)	40.7	(1.8)	29.6	(1.7)
		NS		***		NS		NS	
50-59	66	6.0	(0.3)	10.0	(0.5)	40.2	(2.4)	29.9	(1.9)

Key:

- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% level
- *** Significant at the 99.9% level

N.B. Significance levels apply to immediately adjacent groups

Mean Results for Limb Circumferences within Age Groups: Forces

Table 40(b)

(Standard Deviation in Parenthesis)

MALES

n = 5331

Age (Yrs)	n	Upper Arm (cm)		Calf (cm)		Thigh (cm)		Buttock (cm)	
16	370	27.2	(2.2)	36.6	(2.2)	53.7	(3.7)	92.6	(4.5)
		***		**		***		***	
17-19	1057	28.5	(2.4)	37.0	(2.4)	54.9	(4.1)	93.9	(5.0)
		***		***		***		***	
20-24	1274	29.9	(2.5)	37.8	(2.6)	56.6	(4.3)	96.2	(5.6)
		***		*		***		***	
25-29	792	30.6	(2.7)	38.1	(2.8)	57.3	(4.6)	97.5	(6.0)
		***		NS		NS		***	
30-34	782	31.2	(2.5)	38.1	(2.5)	57.6	(4.0)	98.5	(5.5)
		NS		NS		NS		NS	
35-39	579	31.2	(2.4)	38.0	(2.6)	57.2	(3.9)	98.9	(5.5)
		*		NS		NS		NS	
40-44	269	31.5	(2.4)	38.1	(2.6)	57.1	(4.1)	99.3	(5.6)
		*		NS		NS		*	
45-49	142	31.9	(2.3)	38.2	(2.4)	57.4	(3.9)	100.9	(5.4)
		*		NS		NS		NS	
50-59	66	31.5	(2.7)	37.8	(2.8)	56.5	(4.5)	100.6	(6.8)

Key:
- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% level
- *** Significant at the 99.9% level

NB. Significance levels apply to immediately adjacent groups

Mean Results for Bone Diameters within Age Groups: Civilians   Table 41(a)

(Standard Deviation in Parenthesis)

MALES

n = 1053

Age (Yrs)	n	Ulnar (cm)				Tibial (cm)			Biacromial (cm)			Bi-iliac (cm)		
17-19	42	5.8	NS	(0.4)	NS	9.7	NS	(0.6)	40.0	NS	(1.8)	27.3	*	(1.8)
20-24	145	5.7	NS	(0.3)	NS	9.7	*	(0.4)	40.6	NS	(1.6)	28.1	*	(1.7)
25-29	170	5.8	NS	(0.3)	NS	9.8	NS	(0.5)	40.5	NS	(1.7)	28.6	NS	(1.6)
30-34	116	5.8	NS	(0.3)	NS	9.7	NS	(0.5)	40.5	NS	(1.7)	28.6	NS	(1.6)
35-39	125	5.8	NS	(0.3)	NS	9.8	NS	(0.5)	40.7	NS	(1.9)	28.7	*	(1.9)
40-44	105	5.8	*	(0.3)	NS	9.8	NS	(0.5)	40.3	NS	(1.9)	29.1	*	(1.5)
45-49	107	5.9	*	(0.3)	NS	9.8	NS	(0.5)	40.7	*	(1.7)	29.6	NS	(1.7)
50-64	243	6.0		(0.3)		9.8		(0.5)	40.2		(1.8)	29.9		(1.6)

Key:
- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% level
- *** Significant at the 99.9% level

N.B. Significance levels apply to immediately adjacent groups

Mean Results for Limb Circumferences within Age Groups: Civilians

Table 41(b)

(Standard Deviation in Parenthesis)

MALES

n = 1053

Age (Yrs)	n	Upper Arm (cm)		Calf (cm)		Thigh (cm)		Buttock (cm)	
17-19	42	27.6	(2.6)	36.3	(2.4)	53.7	(4.5)	92.8	(5.6)
		*		*		*		*	
20-24	145	28.6	(2.7)	37.3	(2.3)	55.4	(4.2)	95.2	(5.2)
		***		*		**		***	
25-29	170	29.6	(2.5)	38.0	(2.7)	56.8	(4.4)	97.4	(5.7)
		NS		NS		NS		NS	
30-34	116	29.8	(2.5)	37.6	(2.5)	56.1	(4.0)	97.1	(5.5)
		NS		NS		NS		NS	
35-39	125	30.0	(2.5)	37.7	(2.6)	55.9	(4.2)	97.7	(5.5)
		NS		NS		NS		NS	
40-44	105	29.9	(3.0)	37.7	(2.7)	55.4	(4.4)	98.0	(6.3)
		NS		NS		NS		NS	
45-49	107	30.6	(2.5)	37.8	(2.9)	55.6	(3.9)	99.1	(6.0)
		NS		NS		*		NS	
50-64	243	30.4	(2.4)	37.5	(2.7)	54.6	(3.5)	98.8	(5.0)

Key:

NS Not Significant
* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

N.B. Significance levels apply to immediately adjacent groups.

Comparison of Male Forces Sample with Male Civilian Sample: Diameters and Circumferences

Table 42

(SD in Parenthesis)

Age (yrs)		Ulnar D	Tibial D	Biacromial D	Biiliac D	Upper Arm C	Calf C	Thigh C	Buttock C
16	F	5.8 (0.3)	9.9 (0.4)	39.2 (1.7)	27.4 (1.5)	27.2 (2.2)	36.6 (2.2)	53.7 (3.7)	92.6 (4.5)
	C	-	-	-	-	-	-	-	-
17-19	F	5.8 (0.3)	9.8 (0.5)	39.7 (1.9)	27.5 (1.5)	28.5 (2.4)	37.0 (2.4)	54.9 (4.1)	93.9 (5.0)
		NS	NS	NS	NS	*	NS	NS	NS
	C	5.8 (0.4)	9.7 (0.6)	40.0 (1.8)	27.3 (1.8)	27.6 (2.6)	36.3 (2.4)	53.7 (4.5)	92.8 (5.6)
20-24	F	5.8 (0.3)	9.8 (0.5)	40.3 (1.9)	28.0 (1.6)	29.9 (2.5)	37.8 (2.6)	56.6 (4.3)	96.2 (5.6)
		***	**	*	NS	***	*	**	*
	C	5.7 (0.3)	9.7 (0.4)	40.6 (1.6)	28.1 (1.7)	28.6 (2.7)	37.3 (2.3)	55.4 (4.2)	95.2 (5.2)
25-29	F	5.8 (0.3)	9.9 (0.5)	40.5 (1.9)	28.4 (1.7)	30.6 (2.7)	38.1 (2.8)	57.3 (4.6)	97.5 (6.0)
		NS	*	NS	NS	***	NS	NS	NS
	C	5.8 (0.3)	9.8 (0.5)	40.5 (1.6)	28.5 (1.5)	29.6 (2.5)	38.0 (2.7)	56.8 (4.4)	97.4 (5.7)
30-34	F	5.9 (0.3)	9.9 (0.4)	40.4 (1.9)	28.7 (2.8)	31.2 (2.5)	38.1 (2.5)	57.6 (4.0)	98.5 (5.5)
		***	***	NS	NS	***	*	**	**
	C	5.8 (0.3)	9.7 (0.5)	40.5 (1.7)	28.6 (1.6)	29.8 (2.5)	37.6 (2.5)	56.1 (4.0)	97.1 (5.5)
35-39	F	5.9 (0.3)	9.9 (0.5)	40.4 (1.9)	28.9 (1.7)	31.2 (2.4)	38.0 (2.6)	57.2 (3.9)	98.9 (5.5)
		***	*	NS	NS	***	NS	***	*
	C	5.8 (0.3)	9.8 (0.5)	40.7 (1.9)	28.7 (1.9)	30.0 (2.5)	37.7 (2.6)	55.9 (4.2)	97.7 (5.5)
40-44	F	6.0 (0.3)	9.9 (0.5)	40.6 (1.9)	29.0 (1.5)	31.5 (2.4)	38.1 (2.6)	57.1 (4.1)	99.3 (5.6)
		**	NS	NS	NS	***	NS	***	NS
	C	5.8 (0.3)	9.8 (0.5)	40.3 (1.9)	29.1 (1.5)	29.9 (3.0)	37.7 (2.7)	55.4 (4.4)	98.0 (6.3)
45-49	F	6.0 (0.3)	9.9 (0.4)	40.7 (1.7)	29.6 (1.7)	31.9 (2.3)	38.2 (2.4)	57.4 (3.9)	100.9 (5.4)
		**	NS	NS	NS	***	NS	***	*
	C	5.9 (0.3)	9.8 (0.5)	40.7 (1.7)	29.6 (1.7)	30.6 (2.5)	37.8 (2.9)	55.6 (3.9)	99.1 (6.0)
50-59	F	6.0 (0.3)	10.0 (0.5)	40.2 (2.4)	29.9 (1.9)	31.5 (2.7)	37.8 (2.8)	56.5 (4.5)	100.6 (6.8)
		NS	**	NS	NS	**	NS	**	*
50-64	C	6.0 (0.3)	9.8 (0.4)	40.2 (1.8)	29.9 (1.6)	30.4 (2.4)	37.5 (2.7)	54.6 (3.5)	98.8 (5.0)

Key: All measurements in cms
F = Forces
C = Civilians

*: significant difference at 95% level between the two sample means
**: significant difference at 99% level
***: significant difference at 99.9% level

Mean Values for Diameters in 12 Geographical Areas: Forces Table 43(a)

Region	MALES				FEMALES			
	Ulnar D	Tibia D	Biacrom D	Biiliac D	Ulnar D	Tibia D	Biacrom D	Biiliac D
1. Scotland	5.75	9.75	39.9	28.1	5.11	9.07	35.9	27.5
2. Wales	5.85	9.85	40.1	28.1	5.14	9.17	36.0	27.5
3. N Ireland	5.85	9.80	40.0	28.0	5.09	8.89	36.0	27.2
4. The North	5.85	9.80	40.3	28.3	5.14	9.18	36.4	27.9
5. Yorkshire/ Humberside	5.85	9.85	40.3	28.1	5.11	9.17	36.3	27.9
6. North West	5.85	9.85	40.1	28.2	5.12	9.13	36.0	27.7
7. East Midlands	5.85	9.90	40.2	28.2	5.16	9.17	36.5	27.8
8. West Midlands	5.85	9.85	40.1	28.4	5.08	9.13	35.8	27.3
9. East Anglia	5.90	9.95	40.8	28.7	5.08	9.12	36.0	27.5
10. London	5.90	9.90	40.3	28.5	5.16	9.17	36.6	28.1
11. South East	5.90	9.90	40.2	28.3	5.19	9.20	36.4	27.8
12. South West	5.90	9.85	40.3	28.3	5.12	9.10	36.5	27.6
Range of SE	0.01-0.03	0.01-0.05	0.06-0.19	0.05-0.16	0.24-0.65	0.05-0.13	0.16-0.43	0.15-0.42

Males n = 4723
Females n = 934

All measurements are in cm

Mean Values for Circumferences in 12 Geographical Regions: Forces Table 43(b)

Region		MALES Calf C	Thigh C	Buttocks C	Upper Arm C	FEMALES Calf C	Thigh C	Buttocks C	Upper Arm C
1.	Scotland	37.4	56.2	96.2	29.9	36.2	56.4	95.9	27.7
2.	Wales	37.7	56.8	96.7	30.2	36.9	58.0	98.1	28.3
3.	N Ireland	37.4	55.9	96.0	29.7	35.4	55.6	94.8	27.0
4.	The North	37.9	56.6	96.7	30.0	36.8	57.6	97.3	28.1
5.	Yorkshire/ Humberside	37.6	56.3	96.4	30.0	36.6	57.6	97.8	27.8
6.	North West	37.7	56.3	96.5	30.0	36.6	57.1	96.8	27.8
7.	East Midlands	37.8	56.5	96.8	29.9	36.4	56.9	96.9	27.3
8.	West Midlands	37.6	56.5	96.8	30.0	36.3	56.7	96.0	27.6
9.	East Anglia	37.9	56.4	97.5	30.1	37.3	58.1	98.3	28.6
10.	London	38.0	57.0	97.3	30.3	37.4	57.6	98.5	28.0
11.	South East	37.7	56.3	96.6	29.9	36.7	57.7	97.7	27.6
12.	South West	37.6	56.2	96.5	29.9	36.5	57.4	97.8	27.6
Range of SE		0.08-0.26	0.14-0.42	0.18-0.55	0.08-0.25	0.21-0.66	0.4-1.11	0.5-1.36	0.24-0.65

Males n = 4723 All measurements in cm.

Females n = 934 All means are adjusted for differences in mean age between the geographical groups.

Mean Values for Bone Diameters within 3 Geographical Areas: Civilians — Table 44(a)

Area	MALES Ulnar D	MALES Tibial D	MALES Biacromial D	MALES Biiliac D	FEMALES Ulnar D	FEMALES Tibial D	FEMALES Biacromial D	FEMALES Biiliac D
A. Scotland	5.8	9.8	40.4	29.0	5.1	9.0	36.1	28.2
B. England: North	5.9	9.8	40.6	29.0	5.1	9.0	36.4	28.5
C. England: South	5.9	9.8	40.3	28.7	5.1	9.0	36.5	28.4

Mean Values for Limb Circumferences within 3 Geographical Areas: Civilians — Table 44(b)

Area	MALES Calf C	MALES Thigh C	MALES Buttock C	MALES Upper Arm C	FEMALES Calf C	FEMALES Thigh C	FEMALES Buttock C	FEMALES Upper Arm C
A. Scotland	37.7	55.5	97.5	29.6	35.0	55.0	95.9	26.9
B. England: North	37.6	55.9	97.8	30.1	35.4	55.6	96.7	27.2
C. England: South	37.3	55.1	96.9	29.5	35.3	55.9	97.2	27.3

Civilian Females: n = 1093

Civilian Males: n = 965

All means are adjusted for differences in mean age between the Geographical Areas.

All measurements in cm.

Mean Results for Bone Diameters within Age Groups: Forces

Table 45(a)

(Standard Deviation in Parenthesis)

FEMALES

n = 1086

Age (Yrs)	n	Ulnar (cm)			Tibial (cm)			Biacromial (mm)			Bi-iliac (mm)		
17-19	405	5.1	NS	(0.3)	9.1	***	(0.5)	36.1	NS	(1.6)	27.2	***	(1.6)
20-24	488	5.1	NS	(0.3)	9.2	***	(0.5)	36.3	NS	(1.6)	27.9	NS	(1.7)
25-29	118	5.1	NS	(0.3)	9.1	***	(0.5)	36.2	NS	(1.8)	28.2	NS	(1.7)
30-34	38	5.1	NS	(0.2)	8.9	NS	(0.5)	36.1	NS	(1.7)	27.7	NS	(1.2)
35-39	14	5.2	NS	(0.3)	9.3	NS	(0.4)	37.0	NS	(3.3)	28.2	NS	(1.8)
40-44	13	5.2	NS	(0.2)	9.5	NS	(0.6)	36.6	NS	(1.8)	29.1	NS	(1.3)
45-49	6	5.2	NS	(0.3)	8.9	NS	(0.8)	36.3	NS	(1.4)	28.6	NS	(1.3)
50-59	4	5.5	NS	(0.1)	9.6	NS	(0.2)	37.1	NS	(1.3)	30.4	NS	(0.9)

Key:
- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% level
- *** Significant at the 99.9% level

N.B. Significant levels apply to immediately adjacent groups

Mean Results for Limb Circumferences within Age Groups: Forces

Table 45(b)

(Standard Deviation in Parenthesis)

FEMALES

n = 1086

Age (Yrs)	n	Upper Arm (cm)		Calf (cm)		Thigh (cm)		Buttock (cm)	
17-19	405	27.6	(2.3)	36.6	(2.5)	57.2	(4.2)	96.8	(5.4)
		NS		NS		NS		*	
20-24	488	27.8	(2.5)	36.7	(2.6)	57.4	(4.5)	97.7	(6.1)
		NS		NS		NS		NS	
25-29	118	27.5	(2.6)	36.3	(2.5)	56.8	(4.3)	97.0	(6.1)
		NS		*		NS		NS	
30-34	38	27.4	(2.5)	35.1	(3.2)	56.3	(4.3)	96.6	(5.4)
		NS		NS		NS		NS	
35-39	14	28.8	(2.2)	36.8	(2.2)	59.0	(4.4)	99.7	(7.0)
		NS		NS		NS		NS	
40-44	13	30.4	(4.6)	36.2	(3.3)	58.7	(6.7)	101.2	(9.5)
		NS		NS		NS		NS	
45-49	6	28.2	(2.7)	34.7	(2.3)	56.5	(3.2)	97.9	(5.7)
		NS		NS		NS		NS	
50-59	4	30.8	(3.9)	36.9	(4.0)	60.8	(4.0)	103.1	(6.2)

Key:

- NS Not Significant
- * Significant at the 95% Level
- ** Significant at the 99% Level
- *** Significant at the 99.9% Level

N.B. Significance levels apply to immediately adjacent groups

Mean Results for Bone Diameters within Age Groups: Civilians

Table 46(a)

(Standard Deviation in Parenthesis)

FEMALES

n = 1169

Age (Yrs)	n	Ulnar (cm)	Sig.	SD	Tibial (cm)	Sig.	SD	Biacromial (cm)	Sig.	SD	Bi-iliac (cm)	Sig.	SD
16	6	5.2	NS	(0.2)	9.2	NS	(0.4)	35.4	NS	(0.8)	27.0	NS	(1.1)
17-19	136	5.0	***	(0.2)	8.9	*	(0.5)	36.0	NS	(1.5)	27.2	**	(1.5)
20-24	338	5.1	NS	(0.3)	9.0	*	(0.5)	36.3	*	(1.7)	27.7	NS	(1.6)
25-29	171	5.1	NS	(0.2)	8.9	*	(0.5)	35.9	NS	(2.2)	27.8	NS	(1.7)
30-34	67	5.1	NS	(0.3)	9.0	NS	(0.5)	36.2	NS	(1.8)	28.1	**	(1.7)
35-39	81	5.1	*	(0.3)	9.1	NS	(0.5)	36.5	NS	(1.6)	28.8	NS	(1.7)
40-44	86	5.2	NS	(0.3)	9.2	NS	(0.5)	36.6	NS	(1.6)	29.1	*	(1.7)
45-49	87	5.2	**	(0.3)	9.2	NS	(0.5)	36.8	NS	(1.6)	29.8	NS	(1.6)
50-64	197	5.3		(0.3)	9.2		(0.6)	36.4		(1.6)	29.8		(1.6)

Key:

NS	Not Significant
*	Significant at the 95% level
**	Significant at the 99% level
***	Significant at the 99.9 % level

NB Significance levels apply to immediately adjacent groups

Mean Results for Limb Circumferences within Age Groups: Civilians

Table 46(b)

(Standard Deviation in Parenthesis)

Females

n = 1169

Age (Yrs)	n	Upper Arm (cm)		Calf (cm)		Thigh (cm)		Buttock (cm)	
16	6	26.7	(2.4)	36.1	(2.5)	55.3	(4.4)	94.8	(6.8)
		NS	NS	NS	NS		NS	NS	
17-19	136	25.9	(2.3)	35.4	(2.4)	54.4	(3.9)	93.8	(5.3)
		NS	NS	NS	NS		**	***	
20-24	338	26.3	(2.4)	35.3	(2.5)	55.5	(4.0)	95.6	(5.6)
		NS	NS	NS	NS		NS	NS	
25-29	171	26.4	(2.4)	34.9	(2.8)	55.0	(4.2)	95.2	(6.0)
		NS	NS	NS	NS		NS	NS	
30-34	67	27.0	(2.6)	34.9	(3.0)	54.8	(4.9)	94.0	(12.2)
		NS	NS	NS	NS		NS	*	
35-39	81	27.5	(2.7)	35.2	(2.8)	55.8	(4.5)	97.5	(6.9)
		NS	NS	NS	NS		NS	NS	
40-44	86	28.1	(2.8)	35.3	(2.7)	56.2	(4.4)	98.6	(6.8)
		NS	NS	NS	NS		NS	NS	
45-49	87	28.5	(2.9)	35.8	(2.9)	56.6	(4.7)	100.0	(7.0)
		NS	NS	NS	NS		NS	NS	
50-64	197	29.0	(2.8)	35.3	(2.7)	56.0	(4.5)	99.3	(7.1)

Key:

- NS Not Significant
- * Significant at the 95% level
- ** Significant at the 99% level
- *** Significant at the 99.9% level

N.B. Significant levels apply to immediately adjacent groups

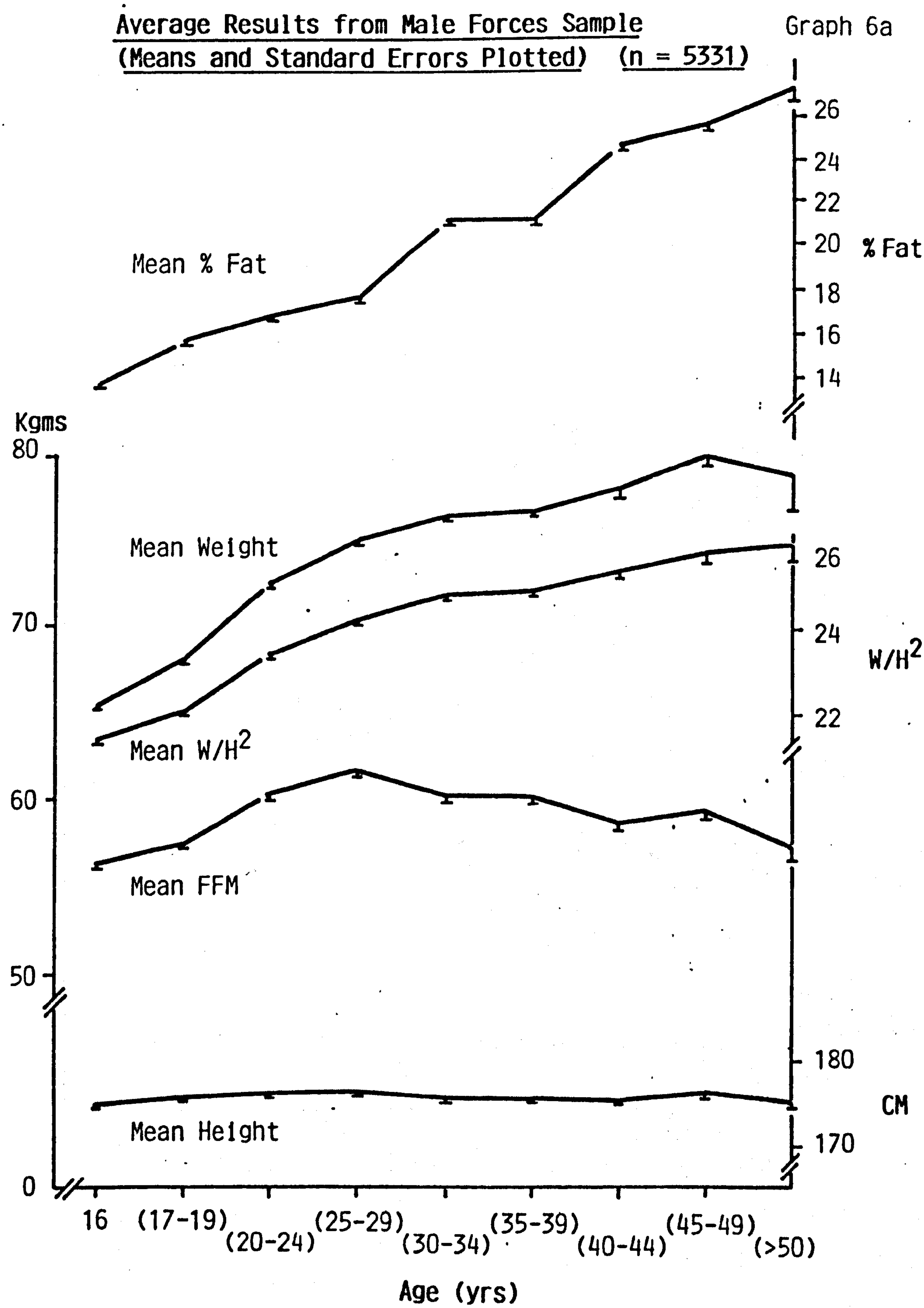
Comparison of Female Forces Sample with Female Civilian Sample: Diameters and Circumferences — Table 47

(SD in Parenthesis)

Age (yrs)		Ulnar D	Tibial D	Biacromial D	Biiliac D	Upper Arm C	Calf C	Thigh C	Buttock C
16	F	-	-	-	-	-	-	-	-
	C	5.2 (.16)	9.2 (.4)	35.4 (.8)	27.0 (1.1)	26.7 (2.4)	36.1 (2.5)	55.3 (4.4)	94.8 (6.8)
17-19	F	5.1 (.26)	9.1 (.48)	36.1 (1.6)	27.2 (1.6)	27.6 (2.3)	36.6 (2.5)	57.2 (4.2)	96.8 (5.4)
		NS	***	NS	NS	***	***	***	***
	C	5.0 (.24)	8.9 (.5)	36.0 (1.5)	27.2 (1.5)	25.9 (2.3)	35.4 (2.4)	54.4 (3.9)	93.8 (5.3)
20-24	F	5.1 (.26)	9.2 (.49)	36.3 (1.6)	27.9 (1.7)	27.8 (2.5)	36.7 (2.6)	57.4 (4.5)	97.7 (6.1)
		NS	***	NS	NS	***	***	***	***
	C	5.1 (.26)	9.0 (.5)	36.3 (1.7)	27.7 (1.6)	26.3 (2.4)	35.3 (2.5)	55.5 (4.0)	95.6 (5.6)
25-29	F	5.1 (.29)	9.1 (.53)	36.2 (1.8)	28.2 (1.7)	27.5 (2.6)	36.3 (2.5)	56.8 (4.3)	97.0 (6.1)
		NS	***	NS	*	***	***	***	*
	C	5.1 (.24)	8.9 (.4)	35.9 (2.2)	27.8 (1.6)	26.4 (2.4)	34.9 (2.8)	55.0 (4.2)	95.2 (6.0)
30-34	F	5.1 (.19)	8.9 (.47)	36.1 (1.7)	27.7 (1.2)	27.4 (2.5)	35.1 (3.2)	56.3 (4.3)	96.6 (5.4)
		NS	NS	NS	NS	***	NS	NS	NS
	C	5.1 (.28)	9.0 (.5)	36.2 (1.8)	28.1 (1.7)	27.0 (2.6)	34.9 (3.0)	54.8 (4.9)	94.0 (12.2)
35-39	F	5.2 (.28)	9.3 (.45)	37.0 (3.3)	28.2 (1.8)	28.8 (2.2)	36.8 (2.2)	59.0 (4.4)	99.7 (7.0)
		NS	NS	NS	NS	*	*	*	NS
	C	5.1 (.31)	9.1 (.5)	36.5 (1.6)	28.8 (1.7)	27.5 (2.7)	35.2 (2.8)	55.8 (4.5)	97.5 (6.9)
40-44	F	5.2 (.24)	9.5 (.61)	36.6 (1.8)	29.1 (1.3)	30.4 (4.6)	36.2 (3.3)	58.7 (6.7)	101.2 (9.5)
		NS	NS	NS	NS	NS	NS	NS	NS
	C	5.2 (.26)	9.2 (.5)	36.6 (1.6)	29.1 (1.6)	28.1 (2.8)	35.3 (2.7)	56.2 (4.4)	98.6 (6.8)
45-49	F	5.2 (.30)	8.9 (.80)	36.3 (1.4)	28.6 (1.3)	28.2 (2.7)	34.7 (2.3)	56.5 (3.2)	97.9 (5.7)
		NS	*	NS	*	NS	NS	NS	NS
	C	5.2 (.26)	9.2 (.5)	36.8 (1.6)	29.8 (1.6)	28.5 (2.9)	35.8 (2.9)	56.6 (4.7)	100.0 (7.0)
50-64	F	5.5 (.15)	9.6 (.19)	37.1 (1.3)	30.4 (0.9)	30.8 (3.9)	36.9 (4.0)	60.8 (4.0)	103.1 (6.2)
		*	***	NS	NS	NS	NS	*	NS
	C	5.3 (.29)	9.2 (.6)	36.4 (1.6)	29.8 (1.6)	29.0 (2.8)	35.3 (2.7)	56.0 (4.5)	99.3 (7.1)

Key: All measurements in cms
F = Forces
C = Civilians

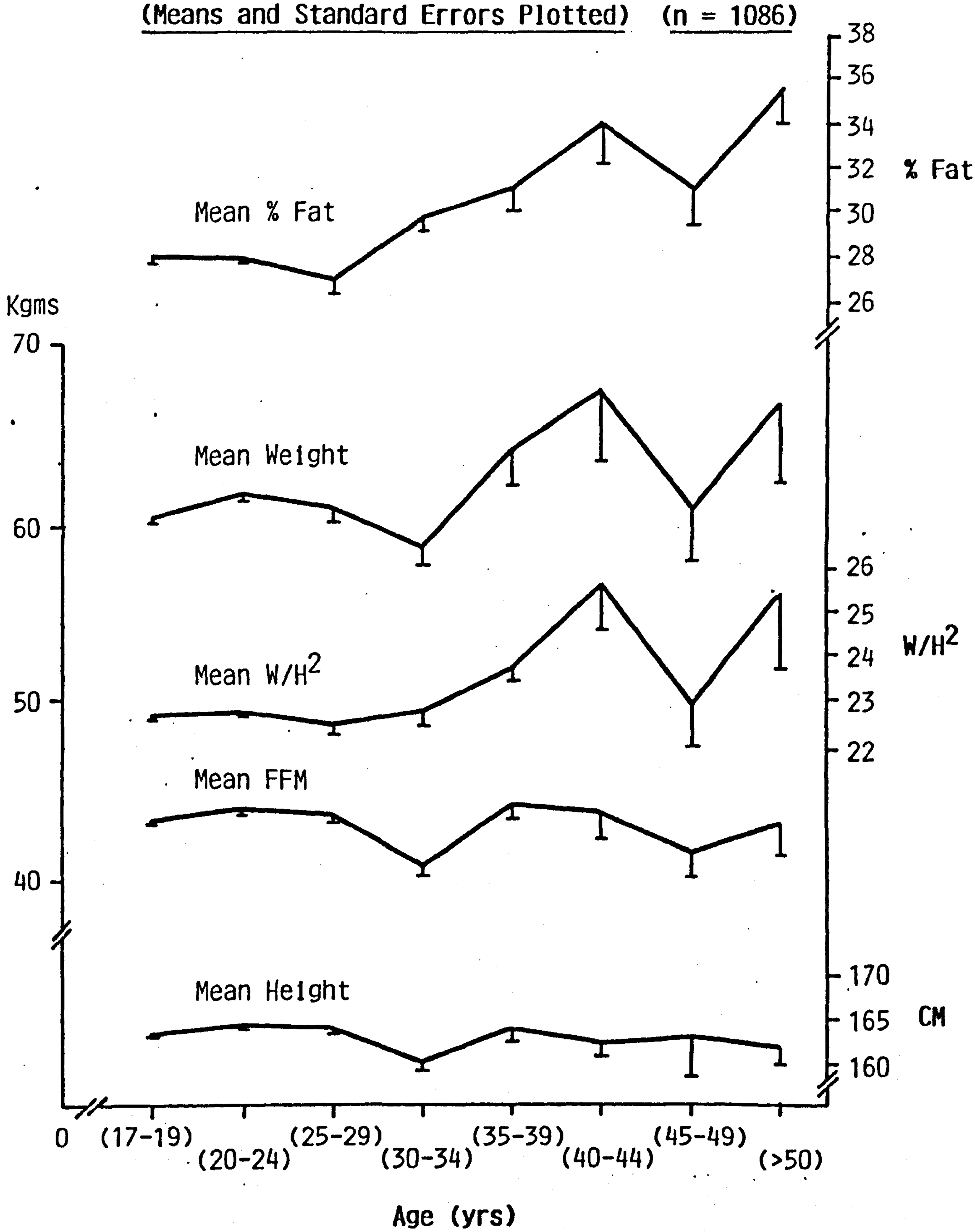
*: significant difference at 95% level between the two sample means
**: significant difference at 99% level
***: significant difference at 99.9 % level



Average Results from Male Forces Sample
(Means and Standard Errors Plotted) (n = 5331)
Graph 6a
Mean % Fat
% Fat
26
24
22
20
18
16
14
Kgms
80
70
60
50
0
Mean Weight
Mean W/H2
Mean FFM
W/H2
26
24
22
180
170
CM
Mean Height
16
(17-19)
(20-24)
(25-29)
(30-34)
(35-39)
(40-44)
(45-49)
(>50)
Age (yrs)

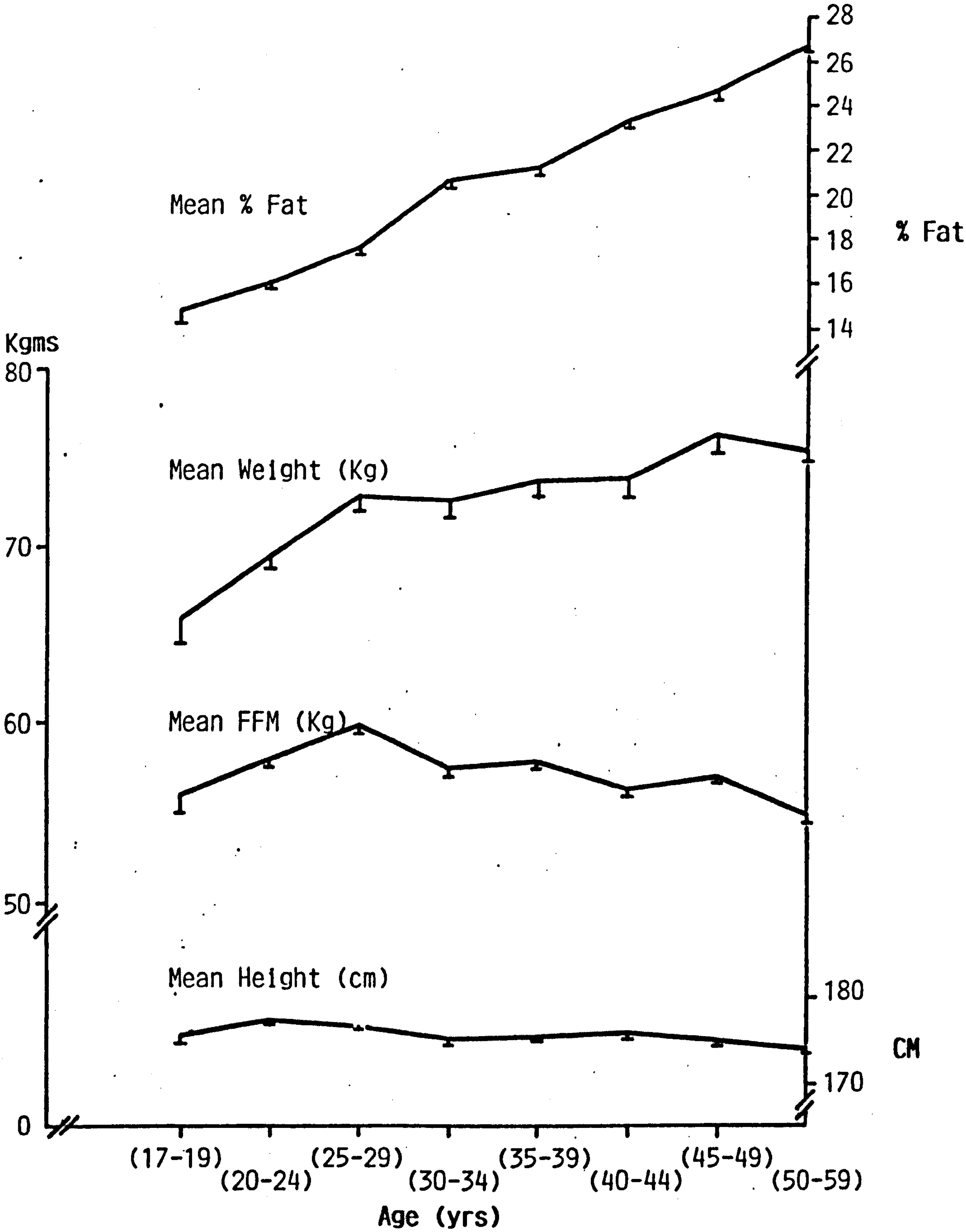
Graph 6b

Average Results from Female Forces Sample
(Means and Standard Errors Plotted) (n = 1086)

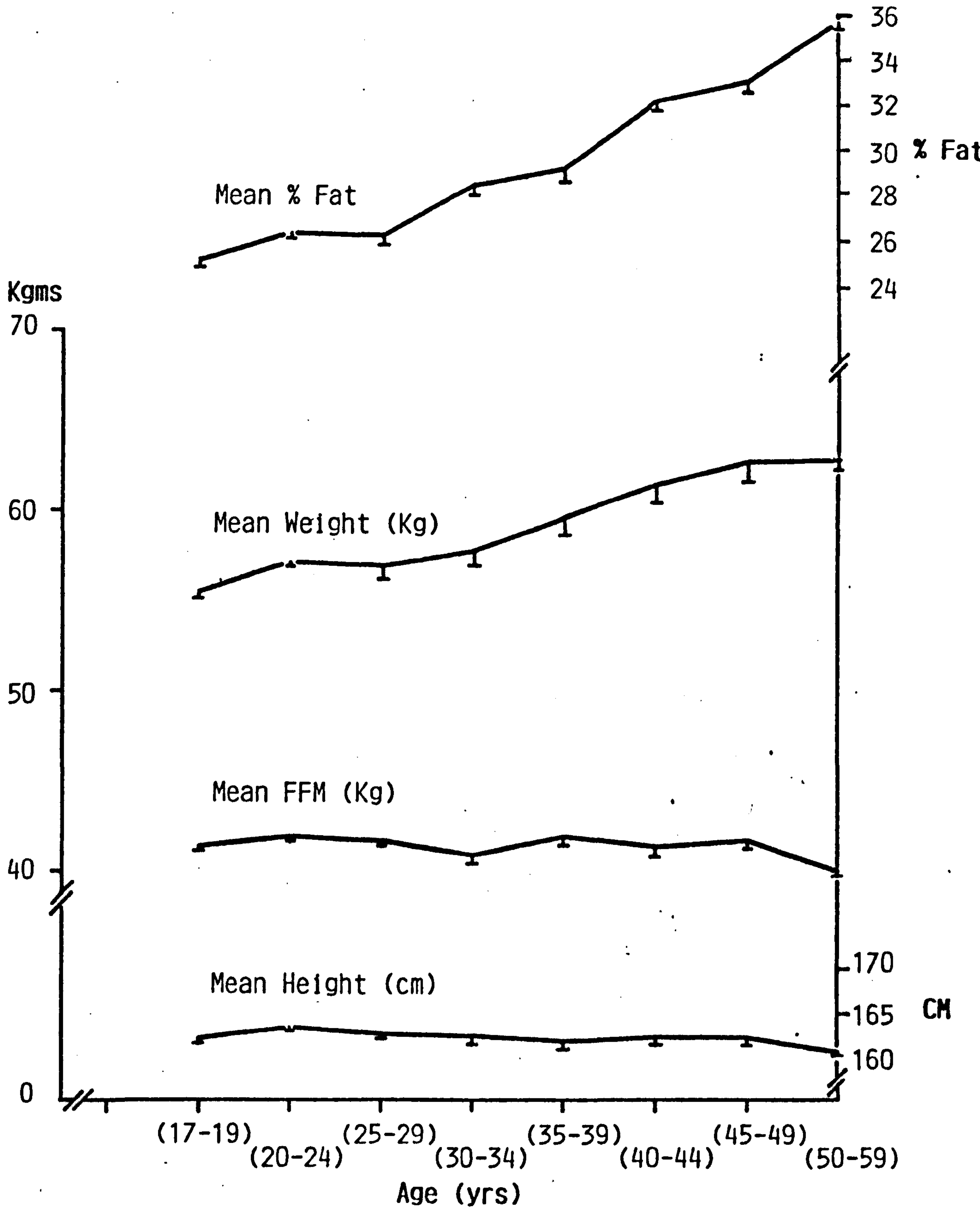


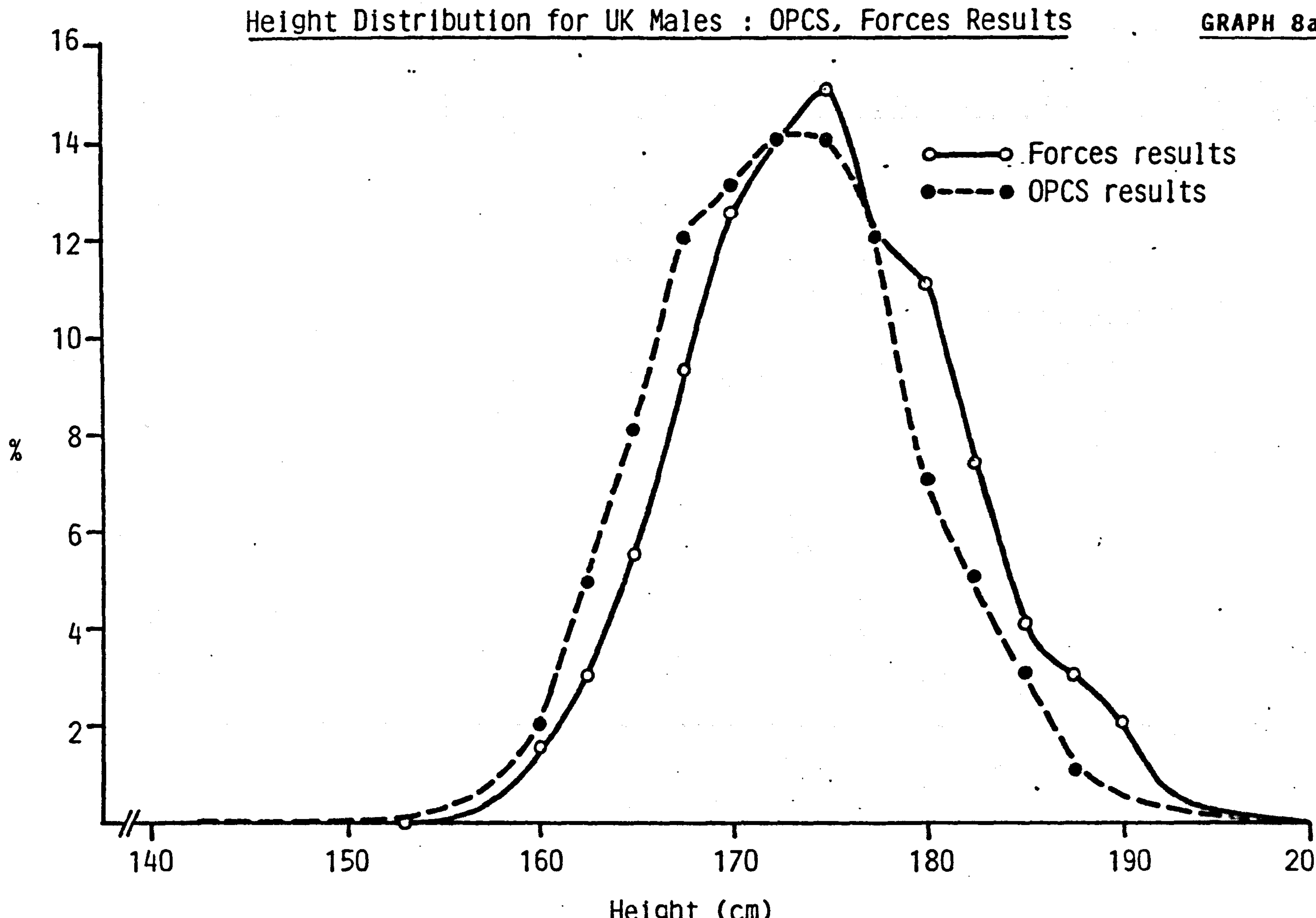
GRAPH 7A

Average Res... ..om Male Civilian Sample
(Means and Standard Errors Plotted) n = 1053



Average Results from Female Civilians Sample
(Means and Standard Errors Plotted) N = 1169

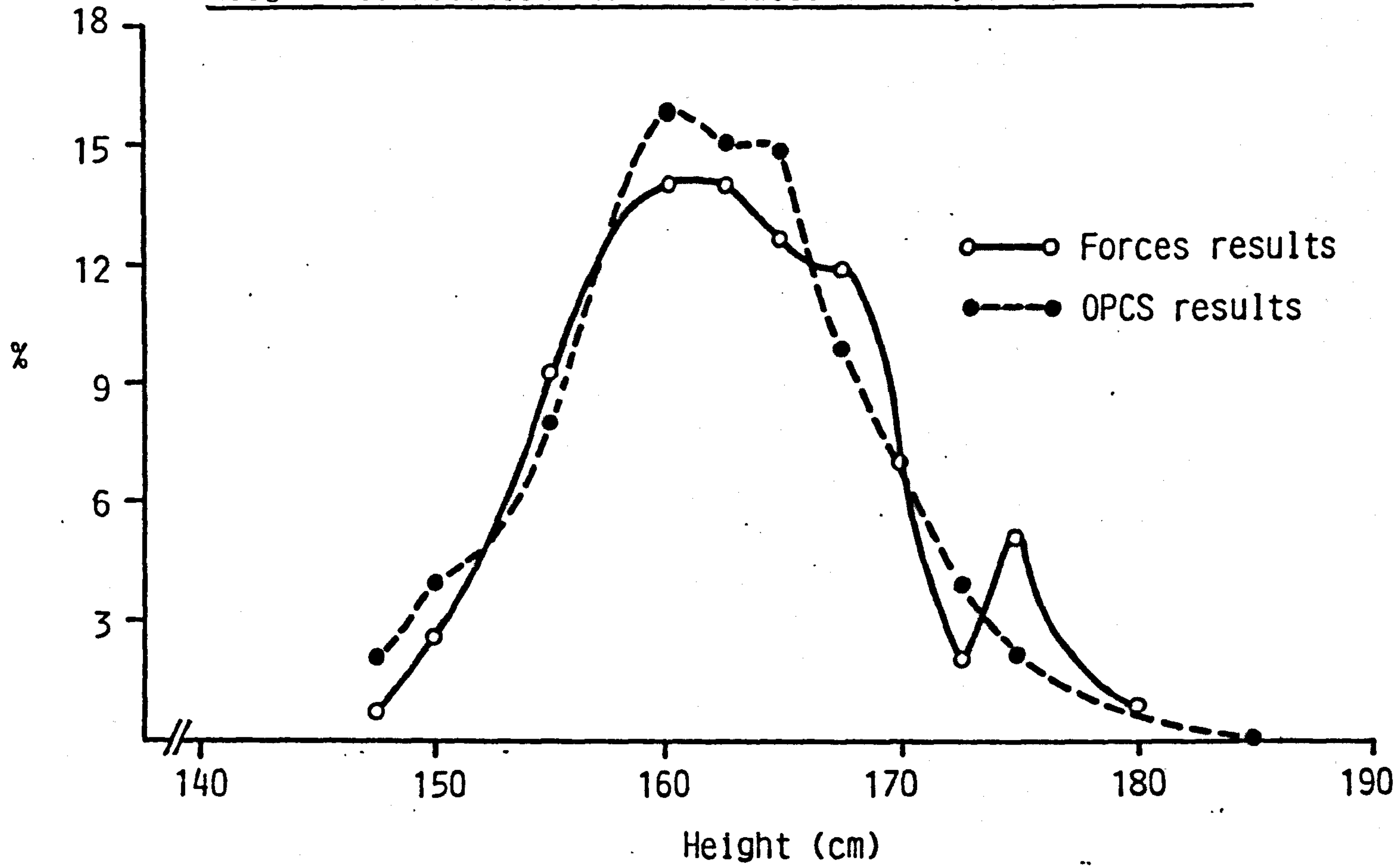




Height Distribution for UK Males : OPCS, Forces Results
GRAPH 8a
Forces results
OPCS results
%
16
14
12
10
8
6
4
2
140
150
160
170
180
190
200
Height (cm)

Height Distribution for UK Females : OPCS, Forces Results

GRAPH 8b



were for the main part only significant because of the large sample sizes.

In general therefore the average Scot would appear to be smaller in most dimensions than the average Londoner. Whether or not he would be 'stockier' is hard to determine since although his limb circumferences and bone diameters did decrease with height, they may not have decreased in proportion and therefore the Scots and Northerners may be relatively speaking 'broader' than the average individual from the south of England.

Because the regional differences in bone diameters and limb circumferences were small it is reasonable to assume that they would not have had much influence on the final statistical analysis.

The differences in height in the Forces sample exhibited a maximum significant difference of 3.6cm in the males and 4cm in the females between Scotland and a southern England region. This cannot necessarily be ignored. However, if mean FFM and the other anthropometric measurements decreased in proportion to the decrease in mean height from the north to the south of the U.K., then the height differences would also be unlikely to greatly affect the final statistical analysis.

Since these proportional changes cannot be assessed, then the final statistical analysis i.e. the regression equations, need to be tested and cross-validated using a sample other than the Forces sample from which they were calculated.

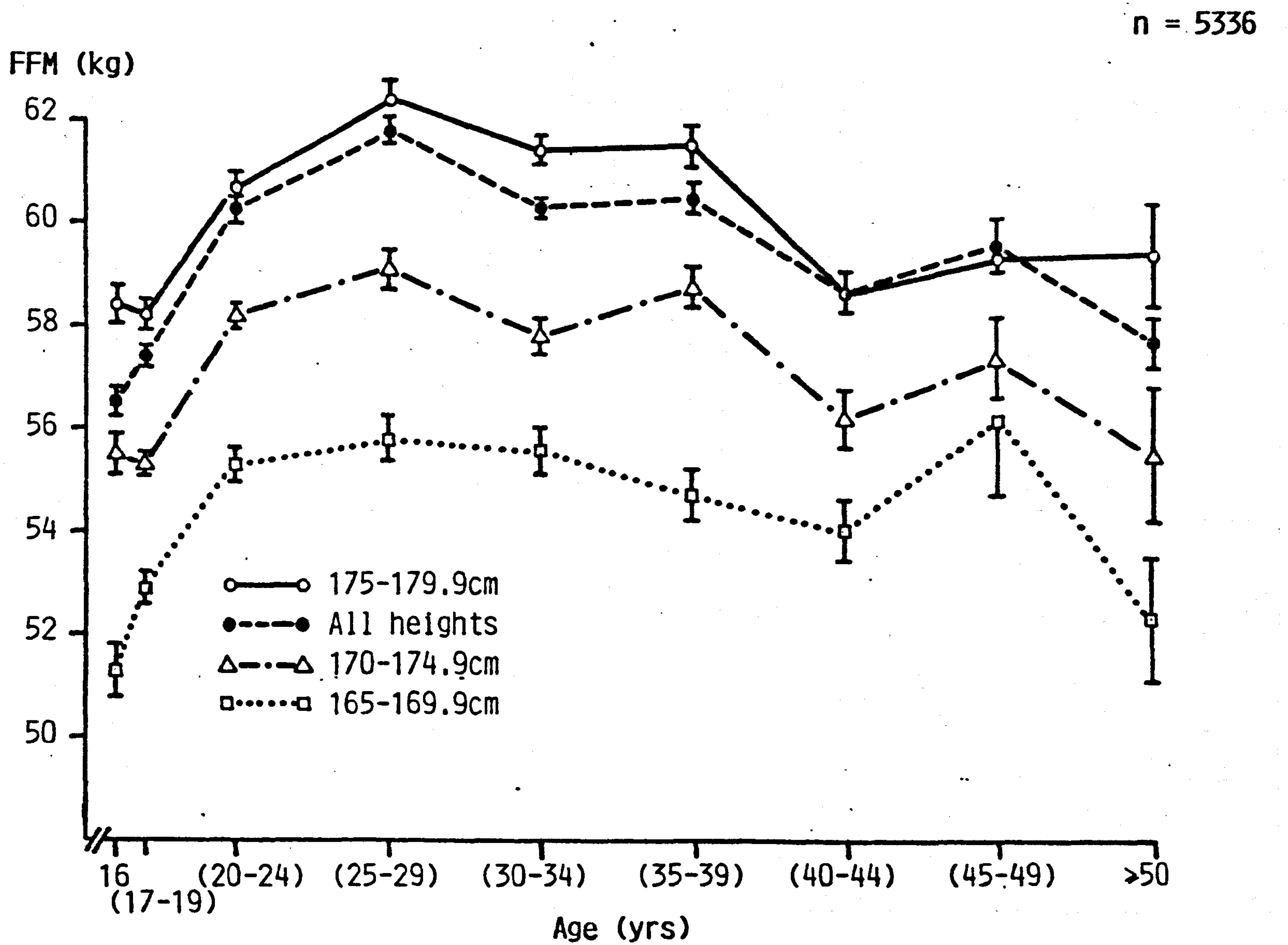
3.2.10. Changes in FFM with Age: Males

(1) Forces

The 5336 Forces males were divided into 9 age groups ranging from 16y to 59y. The mean value for FFM in each group was then plotted against age, as shown in Graph 9(a). (These subjects were described more fully earlier in Section 3.2.6.). Because height influences FFM, the subjects were also subdivided into height groups, and FFM versus age was plotted for 3 of these groups, as shown also on Graph 9(a).

In all the plots, there was a tendency for FFM to rise from the 16y group

FFM vs Age, in Height Groups : Forces Males   Mean ± S.E's are Plotted)   GRAPH 9a



Differences in FFM Between Age Groups: Male Forces — Table 48(a)

Age (yrs)	16	17–19	20–24	25–29	30–34	35–39	40–44	45–49	≥50
16	–								
17–19	-0.91^{*}								
20–24	-3.79^{**}	-2.89^{**}							
25–29	-5.25^{**}	-4.34^{**}	-1.45^{**}						
30–34	-3.74^{**}	-2.84^{**}	0.05^{NS}	1.50^{**}					
35–39	-3.98^{**}	-3.08^{**}	-0.19^{NS}	1.27^{**}	-0.24^{NS}				
40–44	-2.15^{**}	-1.25^{*}	1.60^{**}	3.10^{**}	1.59^{**}	1.83^{**}			
45–49	-3.0^{**}	-2.13^{**}	0.76^{NS}	2.22^{**}	0.71^{NS}	0.95^{NS}	-0.88^{NS}		
≥ 50	-1.19^{NS}	-0.29^{NS}	2.60^{*}	4.06^{**}	2.55^{*}	2.79^{**}	0.96^{NS}	1.84^{NS}	–

Differences calculated as (column value – row value)
*: Significant at 0.05 level
**: Significant at 0.01 level

Differences in Height Between Age Groups: Male Forces — Table 48(b)

Age (yrs)	16	17–19	20–24	25–29	30–34	35–39	40–44	45–49	≥50
16	–								
17–19	-0.91^{NS}								
20–24	-1.47^{**}	-0.56^{NS}							
25–29	-1.64^{**}	-0.73^{NS}	-0.17^{NS}						
30–34	-1.04^{NS}	-0.13^{NS}	0.43^{NS}	0.6^{NS}					
35–39	-0.91^{NS}	0.0^{NS}	0.56^{NS}	0.73^{NS}	0.13^{NS}				
40–44	-0.60^{NS}	0.31^{NS}	0.87^{NS}	1.04^{NS}	0.44^{NS}	0.31^{NS}			
45–49	-1.78^{NS}	-0.87^{NS}	-0.31^{NS}	-0.14^{NS}	-0.74^{NS}	-0.87^{NS}	-1.18^{NS}		
> 50	-0.57^{NS}	0.34^{NS}	0.90^{NS}	1.07^{NS}	0.47^{NS}	0.34^{NS}	0.03^{NS}	1.21^{NS}	–

Differences calculated as (column value – row value)
*: significant at 0.05 level
**: significant at 0.01 level

to a peak in the 25-29y olds, then fall more slowly until the 40-44y group was reached. Thereafter it stayed about level or fell slightly. The FFM value in the oldest age group tended to be on average about 1kg higher than in the 16y olds.

Statistical analysis was carried out on these results, to test the significance of the differences between the means in the different age groups. A Student-Neumann-Kuels test for groups with unequal numbers was used, (SNK Test) and this is described in the Methods chapter.

Table 48(a) gives values for the differences between the age groups in mean FFM, together with their significance levels. There were no significant differences between the age groups over 40y or within the 30y olds, but the former group tended to be significantly smaller in FFM than the latter at the 95% level. Also at this level, all the adjacent age groups, excepting those mentioned above, had significantly different mean FFM values, while many non-adjacent did not. This resulted in a gradual but significant rise in the mean FFM from the 16y olds, to the 25-29y olds, followed by a significant fall to the level found in those over 50y

The FFM peak in the 25-29y olds was on average about 4kg heavier than the 50y group and 5.2kg heavier than the 16y olds, with a mean value of 61.8kg. This value was significantly greater than all other groups at the 99% level.

These changes in mean FFM related to age, could be due to differences in height and/or 'build', where 'build' is used to refer to muscle and bone mass relative to height. The only significant differences in mean height were found between the 16y and 20-24y groups and between the 16y and 25-29y groups Table 48(b), but these differences were less than 2cm. The 2 older groups had significantly higher mean heights than the 16y olds, which was not unexpected since the younger group would not have reached their full growth potential. In order to assess the importance, for the FFM, of these height differences, a subdivision was made into height groups.

(a) Age Groups Subdivided into Height Groups

Three height ranges were chosen (a) 165-169cm, (b) 170-174.9cm and (c)

175-179.9cm. The average values for FFM within each height and age group were calculated. As expected, when FFM was plotted against age for each height range, the results showed a similar pattern to that described above. Tables 49 (a) to (c) show some of these results, for the 3 height groups. Some age groups were excluded from the table purely for the sake of clarity but as Graph 9(a) shows, their results still fitted into the same pattern.

There were significant increases in FFM from the 17y olds to the 20-24y and 25-29y groups. Thereafter there was a gradual decrease in FFM until there were no significant differences between the 16y olds and those over 40y. The mean FFM values in the age groups over 40y, again did not differ significantly from each other. In groups (b) and (c) however, the 40-44y olds had significantly smaller FFM means than the 25-29y olds. These patterns therefore were similar to the pattern found when no height division was made, allowing the conclusion that the pattern was not due to differences in height.

(2) Civilians: Males

1053 civilian males, between the ages of 17y and 64y were divided into 9 age groups as described in the Forces sample. They were not however also divided into height groups, because of the low values for 'n' which would have resulted. Instead, differences in the height distribution within each age group were examined.

Graph 9(b) shows mean FFM plotted against age for both the civilian and Forces samples, and it is obvious that the pattern of change was very similar in both samples. The significance of, and possible reasons for, the differences between the 2 samples were discussed in Section 3.2.7., and will not be discussed again here.

The differences between mean FFM in each civilian age group were calculated and are shown in Table 50(a). The SNK test was again used to test the significance levels of the differences. There were no significant differences in mean FFM between the age groups from 30 to 49y or 17 to 24y. Those over 50y however were significantly smaller in FFM than everyone except the 17-19y olds and the 40-44y olds. The 25-29y olds had significantly larger mean FFM values than all other groups at either the 95% or 99% levels, and these differences ranged from 1.8kg to 4.8kg. This

FFM Differences Between Age Groups: Males Forces

Within Height Groups

Table 49(a)

Age (yrs)	16	20-24	25-29	40-44	≥ 50
16	-		Height Range 165-169.9 cms		
20-24	-4.0**				
25-29	-4.56**	-0.52NS			
40-44	-2.69NS	1.34NS	1.86NS		
≥ 50	-1.0NS	3.04NS	3.57NS	1.70NS	-

Difference calculated as (column - row) *: significant at 0.05 level
**: significant at 0.01 level

Table 49(b)

Age (yrs)	16	20-24	25-29	40-44	≥ 50
16	-		Height Range 170-174.9 cms		
20-24	-2.65**				
25-29	-3.60**	-0.95NS			
40-44	-0.68NS	1.96*	2.91**		
≥ 50	0.0NS	2.65NS	3.60NS	0.68NS	-

Difference calculated as (column - row) *: significant at 0.05 level
**: significant at 0.01 level

Table 49(c)

Age (yrs)	16	20-24	25-29	40-44	≥ 50
16	-		Height Range 175-179.9 cms		
20-24	-2.33**				
25-29	-4.03**	-1.70**			
40-44	-0.32NS	2.00*	3.71**		
≥ 50	-1.06NS	1.26NS	2.96NS	-0.75NS	-

Difference calculated as (column - row) *: significant at 0.05 level
**: significant at 0.01 level

Differences in Mean FFM Between Age Groups: Male Civilians   Table 50(a)

Age (yrs)	17-19	20-24	25-29	30-34	35-39	40-44	45-49	≥50
17-19	-							
20-24	-2.3 NS							
25-29	-4.1 **	-1.8 *						
30-34	-1.7 NS	0.6 NS	2.4 **					
35-39	-2.0 NS	0.3 NS	2.1 *	-0.3 NS				
40-44	-0.5 **	1.8 NS	3.6 **	1.2 NS	1.5 NS			
45-49	-1.4 NS	0.9 NS	2.7 **	0.3 NS	0.6 NS	-0.9 NS		
≥50	0.7 NS	3.0 **	4.8 **	2.4 **	2.7 **	1.2 NS	2.1 *	-

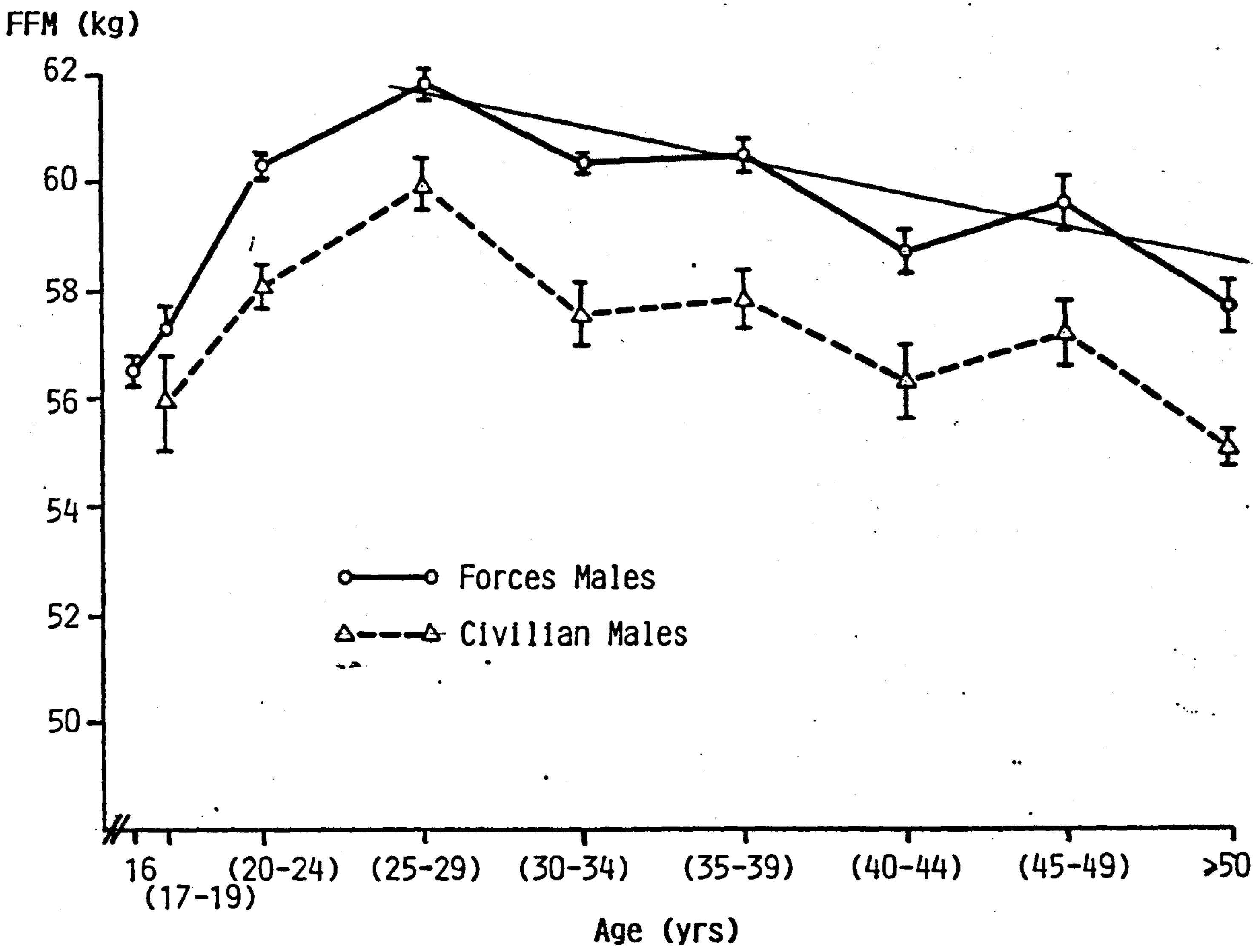
Difference calculated as (column mean - row mean)
*: significant at 0.05 level
**: significant at 0.01 level

Differences in Mean Height Between Age Groups: Male Civilians   Table 50(b)

Age (yrs)	17-19	20-24	25-29	30-34	35-39	40-44	45-49	≥50
17-19	-							
20-24	-1.9 NS							
25-29	-1.0 NS	0.9 NS						
30-34	0.2 NS	2.1 NS	1.2 NS					
35-39	0.0 NS	1.9 NS	1.0 NS	-0.2 NS				
40-44	-0.4 NS	1.5 NS	0.6 NS	-0.6 NS	-0.4 NS			
45-49	0.3 NS	2.2 NS	1.3 NS	0.1 NS	0.3 NS	0.7 NS		
≥50	1.1 NS	3.0 **	2.1 NS	0.9 NS	1.1 NS	1.5 NS	0.8 NS	-

Difference calculated as (column mean - row mean)
*: significant at 0.05 level
**: significant at 0.01 level

FFM vs Age : Forces & Civilian Males (Means ± SE mean are Plotted) GRAPH 9b



FFM peak was preceeded by a gradual increase and followed by a gradual decrease in FFM through the age groups.

The civilians over 50y had a mean FFM significantly smaller than those between 20 and 39y and 40-45y.

In order to check whether these changes were due to differences in mean height or height distribution between the age groups, these differences were calculated and tested for significance with the SNK test. The results are shown in Table 50(b).

Although the height differences ranged from 0 to 3cm, the only difference significant above the 95% level was between the 20-24y olds and those over 50y. The mean height of the 25-29y olds was not significantly different from any other age group at the 95% level. It appeared therefore that height differences did not account for all the changes in mean FFM.

Conclusion: Forces and Civilians

In conclusion therefore, both Forces and civilian male samples demonstrated a peak in mean FFM significant at the 95% or 99% level of significance within the 25-29y group, when compared to all the other age groups. This peak was preceeded by a gradual increase in FFM with age, which was significant in the Forces but not the civilian sample below 19y. It was then followed by a gradual decrease with age, again not significant in the civilian sample beyond the 30-34y group. In the Forces however, between the 20, 30 and 40y olds FFM fell significantly with age at a rate of about 0.13kg/y. In both samples mean FFM in the youngest group was about the same as the oldest group. The civilians over 50y, whose maximum age was 64y compared to the Forces 59y, also had a significantly smaller mean FFM than the adjacent 45-49y olds at the 95% level.

These changes in mean FFM could not be explained by height differences, except to a small extent between the 16y and the 20-24y olds. Between these 2 groups the boys were still growing in stature and this had the effect of increasing mean height by about 1.7cm. There was also a difference of 1cm in height between the Forces 40-44y olds and 45-49y olds which was reflected in the FFM graph.

It is possible therefore that the FFM pattern could be due to differences in 'build' for whatever reason they arose, or to methodological limitations.

Discussion

These observed changes in the average FFM of the male Forces and civilian personnel could be due to several factors:

1. The height independent increase in FFM seen between 16 and 20y was possibly related to exercise habits. Conversely, the decrease seen between 30 and 50y may have been influenced to a small extent by the decrease in exercise levels of these older groups. In order to examine this possibility, the exercise habits of the male Forces and civilians are shown on Table 51.

Table 51

Exercise Habits of the Male Forces and Civilian Samples Within Age Groups

Exercise Level		16y	17-19y	20-24y	25-29y	30-34y	35-39y	40-44y	45-49y	≥50y
Ex 1	F	92%	75%	66%	57%	51%	48%	39%	30%	31%
	C	-	65%	57%	53%	45%	36%	48%	40%	31%
Ex 2	F	8%	25%	34%	43%	49%	52%	61%	70%	69%
	C	-	35%	43%	47%	55%	64%	52%	60%	69%

Forces n = 5297 Civilian n = 1000

Key: Ex 1 - Exercise ≥ twice a week F = Forces

Ex 2 - Exercise < twice a week C = Civilians

The results are expressed in terms of the percent of each age group, in each sample, who exercised at each level. The discrepancy between these values of n, and those quoted earlier were due to the fact that some individuals did not answer the question fully.

Exercise Habits

How much an individual's exercise habits could affect his FFM is not easily quantified since it depends on many factors such as:

(a) the type of exercise; e.g. weightlifting would tend to increase muscle bulk more than a sport such as sprinting,

(b) the vigour with which the exercise is carried out,

(c) the length of continuous time spent on the exercise, and the frequency of the exercise.

A larger proportion of the Forces than of the civilian sample exercised more than twice a week at all ages except the over 50y group, and in both samples this proportion decreased with age. The exceptionally high level of exercise in the Forces 16y olds was probably due to the fact that these boys were all new recruits still undergoing training which included much physical exercise.

It appears unlikely from the results that the exercise patterns could have accounted for all the changes in FFM with age, since while the average activity level between 17 and 29y fell, mean FFM increased. It is uncertain from the data whether the fall in both FFM and activity after 29y were related. It should be noted however that this data does not give information on whether the standards of exercise, in terms of muscular or cardiovascular stress, etc, were comparable for each age group.

To examine further whether it was likely that activity could be related to FFM in this cross-sectional study, the Forces males were grouped into 4 groups, as described below.

1. Exercised $\geq$ twice/week + Active job
2. Exercised $\geq$ twice/week + Sedentary job
3. Exercised $<$ twice/week + Active job
4. Exercised $<$ twice/week + Sedentary job

Jobs classed as 'active' and 'sedentary' are listed in Appendix J and those occupations which did not fall obviously into either category were not included in the analysis. The results for FFM and height in groups 1 and 4 were plotted on Graph 10, and significant differences between equivalent age groups marked.

The only groups with a difference in mean FFM significant at the 95% level or above, were the 25-29y olds and 30-34y olds. Graph 10 also shows the mean height in each age group and it appears that although height obviously influenced FFM, in these 2 age groups there were no significant differences in mean height at the 95% level. If however, the differences were removed, the 20-24y olds would probably also have exhibited activity related FFM differences. Although no quantitative conclusions can be given to these results, it nevertheless appears that, on average, higher activity levels can result in higher than average FFM values, at least in individuals between 25y and 34y. The lack of a difference in the younger groups may have been because of height differences and in particular the significantly larger mean height in the 'sedentary' group between 20-24y.

Another possible explanation for these results however, could be that those males with genetically induced larger-than-average FFM's could have chosen to be more active.

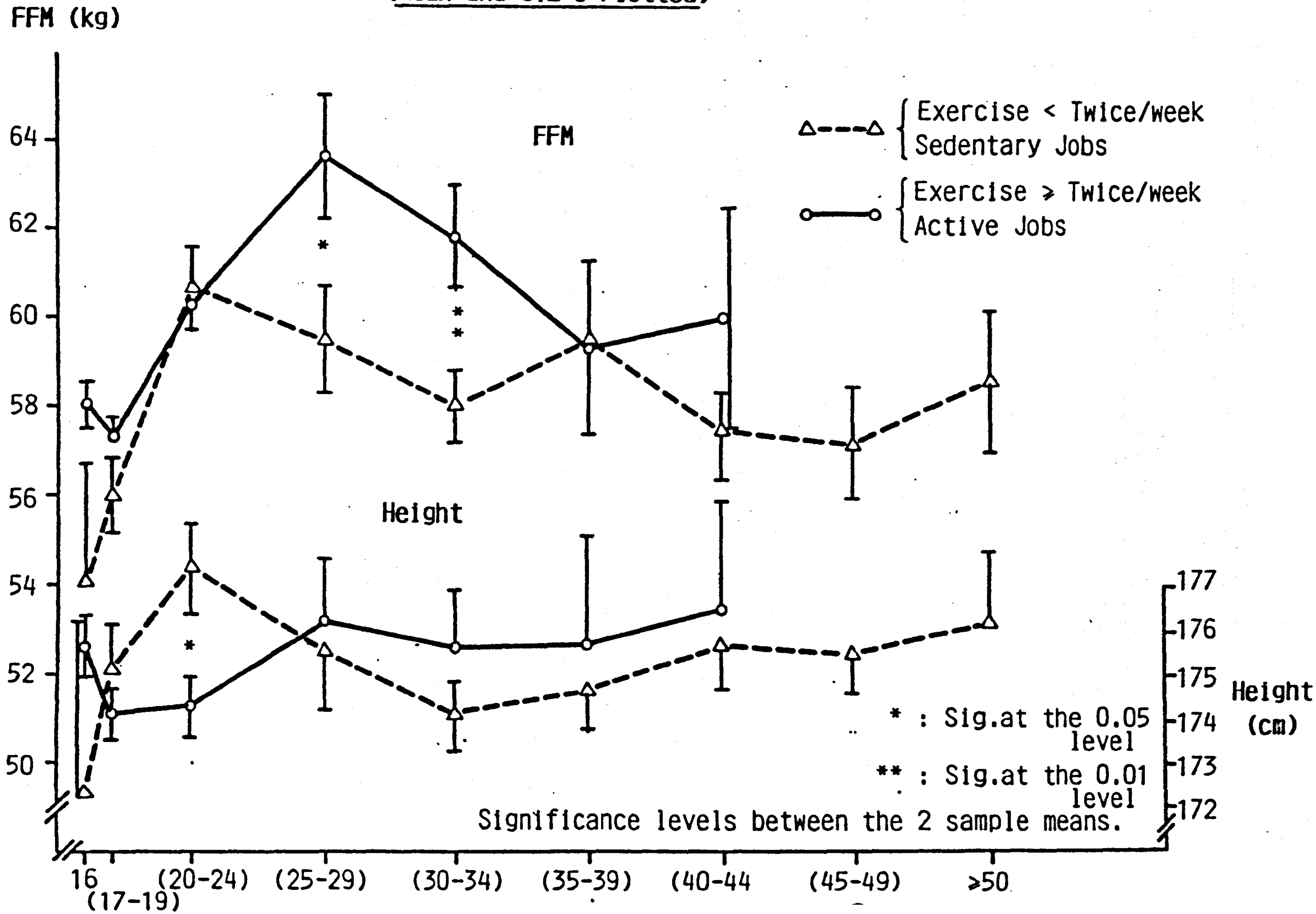
It is also possible that the active older age groups did not carry out their exercise and activity at the same strenuous level as the younger age groups and thus became more similar to the inactive group. As a result the differences in FFM, whether induced genetically or by exercise may have been reduced to non-significant levels.

It is discussed in the next section, but it should be noted that due to secular changes, the males over 30y of age may never have had FFM values similar to the 25-29y olds and therefore it is not suggested that activity patterns accounted for the drop in FFM of about 1.5kg seen in Graph 10 between the 25-29y and 30-34y groups. It is suggested however that activity may have largely accounted for the differences in mean FFM shown on Graph 10 within the 20-24y, 25-29y and 30-34y age ranges.

2. With increasing age many biological changes occur in the body which

Mean FFM vs Age : 'Active' and 'Inactive' Males Service Personnel
(Mean and S.E's Plotted)

GRAPH 10



could affect the FFM. Between the ages of 16 and 20y males are generally still maturing and growing physically. Therefore an increase in mean FFM is expected.

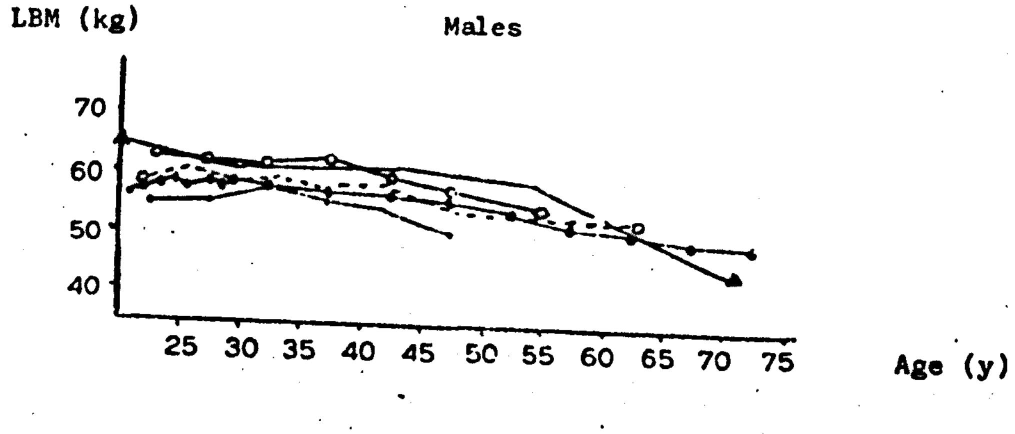
The process of ageing beyond about 20y old is more difficult to describe and quantify and is affected by both environmental and genetic factors.

Skeletal changes also occur with age both in bone density, which is discussed in the next section, and in bone mass. The remodelling of some bones with age however, i.e. changes in both width and length, the inter-individual variability and the degree of independence between the changes in different bones make these changes difficult to quantify. It is believed nevertheless that after about 40yrs of age bone mass progressively decreases. (Suzanne, 1980), although at very slow rates below 60y of age.

Longitudinal decreases in height with age have been documented, but these have generally only occurred after the age of about 45y (Miall et al, 1967; Suzanne, 1974, 1977).

Changes in FFM with age have been demonstrated by other workers using cross-sectional studies on male subjects (Forbes et al, 1970; Burmeister and Bingert, 1967; Myhre and Kessler, 1966; Krzywichi and Chinn, 1967; Anderson and Langham, 1959; Woodward et al, 1960)

Graph 11



Copied from Forbes and Reina (1970)
Cross-sectional data on LBM (from 40k)
-o- Forbes and Reina (1970); -•- Burmeister and Bingert (1967);
-▲- Myhre and Kessler (1966); -.- Krzywichi and Chinn (1967);
—o— Anderson and Langham (1959).
Burmeister and Bingert's data are medians; the others are means.

In all these studies, 'LBM' was estimated from 40K. Although there is a degree of variation (possibly due to subject selection and calibration of the 40K counters) the trend appears to be similar to the trend found in this study. While % fat rose progressively with age, mean weight rose till about 50y of age, after which it tended to decline slightly. FFM however peaked around the mid-20's, after which it declined slowly for about 2 decades and then more rapidly from about 50y of age.

Several other studies have examined cross-sectional changes in FFM using methods other than 40K counting, such as TBW methods and densitometry, and although they have still reported a decline with age, it has generally been smaller than the decline of about 3kg per decade shown on Graph 11. Brozek (1952) for instance reported a loss of only about 1.1kg per decade between the ages of 25 and 50y. The reasons for these differences may be methodological and related to other changes in body composition with age. The relative constancy of the ECF volume compared to other body components could cause the TBW method to overestimate FFM when compared to the 40K method. There is also the fact that the 40K method assumes that the K content of the FFM density is fairly constant with age. Skeletal muscle however has a K content of about 100m mol/kg, marrow-free bone a content of about 20m mol/kg and fat-free adipose tissue a value somewhere between 25 and 65m mol/kg. A change in the relative proportions of these components would therefore upset the assumptions behind the two methods. A disproportionately large loss of skeletal muscle, for instance, would reduce the potassium content of FFM but increase its density causing the 40K method to underestimate and densitometry to overestimate FFM. Nevertheless the data suggest a possible decline in FFM from about the late 20s or early 30s.

The problem with these results is that the age related changes in FFM may have been due to secular population trends as opposed to longitudinal changes and the number of longitudinal studies is very limited. Those which have been carried out, generally did not measure fat content (Sorlie et al, 1980; Rose et al, 1977; Noppa et al, 1980). Forbes (1970, 1976) however examined longitudinal data both from his laboratory and from the literature and again concluded that there is a decline in FFM with age, although it is not seen in all subjects. Again, the decline is seen from about 30y of age but the rate of loss reported depended both on age and on the method used for assessing FFM. As with the cross-sectional data, the rate of decline appears to be slower in the early, compared to the late, adult years and the 40K method overestimated the loss when compared to the densitometric method. Using the potassium method, Forbes (1976) estimated an average loss of 0.32kg/y in males, while Forbes and Reina (1970) reported a loss of about 0.2kg/y in 1 individual using the densitometric method.

These reductions in FFM with age, which are of the order of 10kg between the ages of 25 and 55y in the data of Forbes (1976) and 6kg for the same age difference in Forbes and Reina (1970), appear rather large but probably at least indicate a real loss. The differences between the results of the two studies are probably methodological in origin, as discussed earlier.

There appears to be quite a degree of variation in the literature on the exact rate of loss and the age at which it starts and it would be interesting to examine the degree to which exercise and nutrition affect this decline. The results of Brozek (1952) and one of the subjects examined by Forbes and Reina (1970) suggest that exercise at least is influential. The discussion of our results in the preceeding section also support this idea to some extent.

One factor which would work in the opposite direction i.e. to increase FFM, is the increase in fat content with age. Since this fat is stored in the form of adipose tissue i.e. 64% fat, 22% 'cell residue' and 14% extracellular fluid (Brozek et al, 1963) an increase in fat causes a related increase in FFM. Within the age groups examined, therefore, the overall fall in mean FFM caused by an age-related decline would be slightly damped by an increase in adipose tissue.

The pattern of changes in FFM found in this study may not be entirely longitudinal, but probably also includes cross-sectional variations. Longitudinal changes could account for the rise between 16y and 20y, the slight decline at a rate of about 0.13kg/y from about 30y and a slightly more steep decline beyond about 45y of age. They could not however account for the peak in the 25-29y group.

3. The pattern could be influenced by the methodology used to calculate FFM from skinfolds.

Fat content was calculated using the equations of Durnin and Womersley (1974), with a separate equation for each of the age ranges 16-19y, 20-29y, 30-39y, 40-49y and 50y. As was pointed out in the methods section, beyond about 20y and mainly related to the redistribution of fat, any one value for the sum of 4 skinfolds is associated with increasing percent fat values as ageing progresses and therefore from one age equation to the next there is a slight jump in predicted fat content. Between the 17-19y and 20-29y olds there is actually a slight fall in percent fat. In the order of age groups listed, from 16y these 'jumps' are approximately -0.3%, 3%, 2% and 1.5%, and they were reflected in 'jumps' on Graph 9(b).

Although these changes do represent actual increases in fat content with age, percent fat does not increase in jumps and therefore to be more realistic the graph ought to be smoothed out between the 20-29y and 50y groups.

To this end, a regression of FFM against age was calculated for the Forces sample from about the mid-point of the 20-29yr olds, i.e. 24y, to 56y. This line of equation: FFM = 64.75 - 0.125 Age, was plotted on Graph 9(b). It was not considered necessary to smooth the graph below about 24y, because in that region the 'jump' between age equations was small.

The corrections relevant for each age group in order to bring the average values of FFM on to this line and smooth out the 'jumps', are given in Table 52 below.

Table 52

FFM 'Corrections' for each Forces Male Age Group; Resultant FFM and % Fat

Age (y)	16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	≥50
Correction (kg)	-	-	-	-0.2	0.7	-0.15	1.05	-0.5	0.75
'Corrected' FFM (kg)	56.7	57.4	60.3	61.6	61.0	60.3	59.7	59.1	58.0
'Corrected' % Fat	13.4%	15.6%	16.6%	17.7%	20.1%	21.2%	23.2%	26.1%	26.2%

The 'corrected' values of percent fat are also shown, and it may be that these smoothed FFM and percent fat values are more realistic since in reality changes generally occur gradually.

Although these corrections smoothed the pattern in Graph 9, they did not eliminate the general trend for FFM to decrease with age. The 'corrected' values still give a rate of decrease of about 1.3kg per decade.

4. The pattern could be an artifact of the method used to calculate FFM from body density.

Fat content was calculated using the equations of Durnin and Womersley (1974). If percent fat was underestimated in the younger males and/or overestimated in the older males, this could explain the pattern of changes.

Womersley (1974), in discussing the skinfold method for estimating body density, pointed out that the decrease in skinfold compressibility with age, and changes in fat distribution and the proportion of fat situated subcutaneously are largely taken into account when regression equations relevant to each age and sex group are used. When the predicted density is converted into a value for fat content however, the error is increased due to uncertainty about the value to choose for the density of FFM. The equation of Siri (1956):

$$\%\ \text{fat} = \left(\frac{4.95}{\text{Density}} - 4.50\right) \times 100$$

is used for all age and sex groups, and assumes densities for FFM and fat of 1.1 x 10^3 kg m^{-3} and 0.9 x 10^3 kg m^{-3} respectively.

It is known however that changes in FFM density do occur with age. The approximate composition of FFM is shown below.

Table 53

Variable	% of FFM	Density
Water	72%	0.9934 kgm^{-3}
Protein	20%	1.34 kgm^{-3}
Mineral	7%	3.00 kgm^{-3}

With the highest density, the most likely source of error is the FFM mineral content. Lindahl and Lindgren (1962); Baker and Angel (1965); Garn, Rohmann and Wagner (1967); Nordin (1973) and many other workers, have recorded decreases in bone mineral content with age. There appears to be little change in young adulthood but thereafter females appear to lose more bone mineral than males. The exact ages at which these changes occur are not known but females appear to start this loss at a younger age and different bones show different patterns of change and different original densities.

Sorenson, Mazess, Smith, Clark and Cameron (1968) used a photon absorptiometric method to measure mineral content of a transverse path of the radius, in 327 males and females between 6 and 17y and 390 adults between 18 and 75y. They found a gradual increase in mineral content from about 0.5g/cm bone to about 1.3g/cm bone at age 20y in males, little change until about 50-60y, then a gradual decrease to about 1.2g/cm of bone at 75y. Female mineral content losses rose more slowly to a peak of about 1g/cm of bone at age 30-35y, then declined to about 0.7g/cm by age 80y.

Mainland (1957), however, pointed out the differences between different bones. He found that while the density of the middle phalanx of the fifth finger decreased with age, the densities of the metacarpel, lunate, capitate and radius bones did not. The exact change with age can therefore only be estimated.

In general, Durnin and Womersley (1974) estimated decreases in bone mineral content of between 8-15% in males between 50-70y and from 18-30% in females between 45-75y. The worst fall of 15% in males would represent a fall in FFM density of approximately 0.006 x 10^3 kg/m^3. Using the equation of Keys and Brozek (1953):

$$\% \text{ Fat} = \frac{1}{D}\left(\frac{d_1 \ d_0}{d_0 - d_1}\right) - \frac{d_1}{d_0 - d_1}$$

D = body density
d_1 = fat density
d_0 = FFM density

this would represent an overestimation in fat content of approximately 2% body weight. Since these mineral changes do not seem to be important until well into middle age, it does not seem probable that they account for the pattern of FFM changes seen in the male samples in this study.

FFM density is also altered by changes in total body fat content. In vivo, most of the body's fat is stored in adipose tissue which comprises about 64% fat, 22% cell residue and 14% water, and has a fat free density of approximately 1.047 x 10^3 kgm^{-3}.

The increase in fat content from 15% to 27% seen in our male sample was estimated by Durnin and Womersley (1974) to reduce FFM density of 1.106 x 10^3 kgm^{-3} to a density of about 1.103 x10^3 kgm^{-3} and thus overestimate fat content by about 1% in the oldest age group.

Changes with age in protein content and therefore muscle mass, or in water content, would be unlikely to be of sufficient magnitude to influence greatly the FFM density. Inter-individual changes are unlikely to be of great importance when examining the average values in this sample, because of the large sample sizes involved.

In conclusion from the discussion and figures above, it appears unlikely that age-related changes in FFM density were responsible for more than a slight overestimation in fat content with age, reaching a likely maximum of slightly over 1% of body weight in the oldest male age group.

Although densitometry has an associated uncertainty of about ± 4% of body weight (Bakker and Stuikenkamp 1977) when expressed as a standard deviation, because of the large sample sizes in this study there is no reason to believe that this error would vary greatly between the age groups.

Summary

The observed pattern of changes in mean FFM with age were probably due to many factors.

1. Age-related FFM growth between the ages of about 16y and 20y, which was dependent on both an average increase in height and 'build'.

2. Exercise habits within the 25-29y, 30-34y and possibly 20-24y groups. High activity levels i.e. exercising twice a week or more and holding an active job, independently of height appeared to increase the mean FFM in these age groups compared to less active individuals. This produced a general peak in the pattern of FFM changes in the 25-29y group and a raised level in the 30-34y olds. Why this should cause such a large peak and why the activity related differences occurred at these particular age groups only, are both unexplained points.

3. An age-related decline in FFM at a rate of about 0.13kg/y, from the age of about 30y.

4. Cross-sectional as opposed to longitudinal differences between the age groups.

5. Methodological factors. The 'jumps' in FFM seen with increasing age from the 25-29y group were considered to be methodological and the 'smoothed' values are shown on Table 52. Changes in FFM density according to the literature are unlikely to occur to any significant extent until

about the mid-40's. Thereafter, using the equation of Siri (1956) may slightly overestimate percent fat and thus underestimate FFM by a maximum of about 3% body weight by the age of 70y. These changes may have accounted for the gradual fall in mean FFM beyond the age of 40y.

3.2.11. Changes in FFM with Age: Females

The 1086 Forces females and 1070 civilian females described in Tables 30 and 31, were divided into 9 age groups in the same manner as the male sample. Mean values for both FFM and height in each group were then plotted against age as shown in Graph 12. Differences between the 2 samples were discussed earlier in Section 3.2. SNK tests were carried out to test the significance of the differences between the means of each age group and these are shown on Tables 54(a) and 55(a). In the Forces sample, the 30-34y group had a mean FFM significantly smaller at the 95% level than the 25-29y and 17-19y groups and smaller at the 99% when compared with the 20-24y group. There was no significant differences between the other groups and the maximum significant difference was 2.9kg.

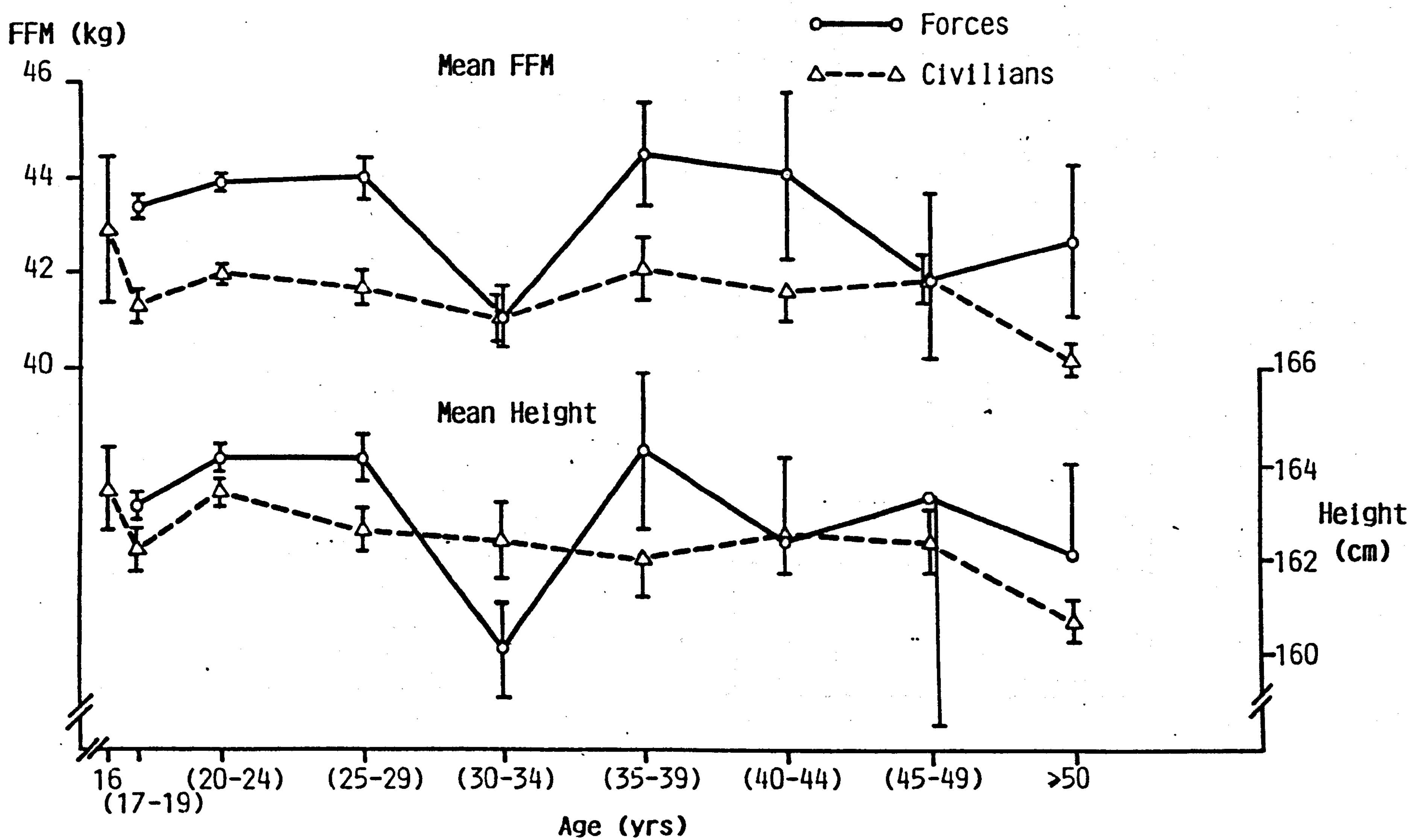
In the civilian sample, the only significant differences in FFM at the 95% or 99% levels were found between the 50-64y group and the groups 20-24y, 25-29y, 30-39y and 45-49y. The maximum significant difference was 1.9kg, with the 50-64y olds having the smaller value compared to the other ages.

On examining the average differences in height between the age groups shown in Tables 54(b) and 55(b), it can be seen that they followed the same pattern of changes as FFM and therefore probably explain most of the FFM changes. The only significant differences in the Forces sample at the 95% or 99% levels were again between the 30-34y group and the 25-29y, 17-19y and 20-24y groups. These differences ranged between 3 and 4cm. The civilians showed significant differences in mean height of 2.7cm and 1.9cm between the 50-64y group and the 20-24y and 25-29y groups, at the 99% and 95% levels respectively.

From this data, it therefore appeared that mean FFM did not change with age to an important or significant extent in the female age range examined. The civilians however, who had an upper age limit of 64y compared to the Forces' 55y appeared to show a slight, significant decrease in mean FFM between the 50-64y and some younger age groups. This may have been related

GRAPH 12

FFM vs Age : Forces & Civilian Females (Means and S.E's are Plotted)



Differences in Mean FFM Between Age Groups: Female Forces Table 54 (a)

Age (yrs)	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-55
17-19	–							
20-24	-0.5 NS							
25-29	-0.6 NS	-0.1 NS						
30-34	2.3 *	2.8 **	2.9 *					
35-39	-1.1 NS	-0.6 NS	-0.5 NS	-3.4 NS				
40-44	-0.7 NS	-0.2 NS	-0.1 NS	-3.0 NS	0.4 NS			
45-49	1.5 NS	2.0 NS	2.1 NS	-0.8 NS	-2.6 NS	2.2 NS		
50-55	0.7 NS	1.2 NS	1.7 NS	-1.6 NS	1.8 NS	1.4 NS	-0.8 NS	–

Differences calculated as (column mean - row mean)
*: significant at 0.05 level
**: significant at 0.01 level

Differences in Mean Height Between Age Groups: Female Forces Table 54(b)

Age (yrs)	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-55
17-19	–							
20-24	-1.0 NS							
25-29	-1.0 NS	0.0 NS						
30-34	3.0 *	4.0 **	4.0 *					
35-39	-1.2 NS	-0.2 NS	-0.2 NS	-4.2 NS				
40-44	0.7 NS	1.7 NS	1.7 NS	-2.3 NS	1.9 NS			
45-49	-0.2 NS	0.8 NS	0.8 NS	-3.2 NS	1.0 NS	-0.9 NS		
50-55	1.0 NS	2.0 NS	2.0 NS	-2.0 NS	2.2 NS	0.3 NS	1.2 NS	–

Differences calculated as (column mean - row mean)
*: significant at 0.05 level
**: significant at 0.01 level

Differences in Mean FFM Between Age Groups: Female Civilians — Table 55(a)

Age (yrs)	16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-64
16	—								
17-19	1.6^{NS}								
20-24	0.9^{NS}	-0.7^{NS}							
25-29	1.2^{NS}	-0.4^{NS}	0.3^{NS}						
30-34	1.9^{NS}	0.3^{NS}	1.0^{NS}	0.7^{NS}					
35-39	0.8^{NS}	0.2^{NS}	-0.1^{NS}	-0.4^{NS}	-1.1^{NS}				
40-44	1.3^{NS}	-0.3^{NS}	0.4^{NS}	0.1^{NS}	-0.6^{NS}	0.5^{NS}			
45-49	1.0^{NS}	-0.6^{NS}	0.1^{NS}	-0.2^{NS}	-0.9^{NS}	0.2^{NS}	-0.3^{NS}		
50-64	2.7^{NS}	1.1^{NS}	1.8^{**}	1.5^{*}	0.8^{NS}	1.9^{*}	1.4^{NS}	1.7^{*}	—

Difference calculated as (column mean - row mean)

*: significant at 0.05 level
**: significant at 0.01 level

Differences in Mean Height Between Age Groups: Female Civilians — Table 55(b)

Age (yrs)	16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	50-64
16	—								
17-19	1.3^{NS}								
20-24	0.1^{NS}	-1.2^{NS}							
25-29	0.9^{NS}	-0.4^{NS}	0.8^{NS}						
30-34	1.1^{NS}	-0.2^{NS}	1.0^{NS}	0.2^{NS}					
35-39	1.5^{NS}	0.2^{NS}	1.4^{NS}	0.6^{NS}	0.4^{NS}				
40-44	1.0^{NS}	-0.3^{NS}	0.9^{NS}	0.1^{NS}	-0.1^{NS}	-0.5^{NS}			
45-49	1.1^{NS}	-0.2^{NS}	1.0^{NS}	0.2^{NS}	0.0^{NS}	-0.4^{NS}	0.1^{NS}		
50-64	2.8^{NS}	1.5^{NS}	2.7^{**}	1.9^{*}	1.7^{NS}	1.3^{NS}	1.8^{NS}	0.7^{NS}	—

Differences calculated as (column mean -row mean)

*: significant at 0.05 level
**: significant at 0.01 level

to changes in FFM density as described in the male section.

Within these particular populations of women, it is unlikely that the levels of physical activity had an appreciable influence on FFM.

Cross-sectional studies carried out by other groups (Forbes et al, 1970; Burmeister et al, 1967; Anderson et al, 1959; Woodward et al, 1960) also showed little change in mean FFM until about 50y of age, after which the decline was still less rapid than in males. These findings support the results of this study.

Longitudinal data on FFM changes in females is quite scarce, but Forbes et al (1976), using the 40K counting method did find a decline with age of about 0.2kg/y which was smaller than the male decline. The age at which this decline started however was not clear from the data provided.

3.3. LEVELS OF FATNESS RELATED TO AGE: FORCES AND CIVILIANS

3.3.1. Males

Table 56 shows the relationship between age and fat content in the Forces and civilian male samples

Table 56

Mean Fat Content in Each Age Group

Age (y)	16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	≥ 50
Forces % Fat	13.4	15.4	16.6	17.4	21.0	21.0	24.6	25.5	27.2
Civ % Fat	-	14.8	16.0	17.5	20.6	21.2	23.4	24.7	26.8

Forces n = 5331 Civilian n = 1053
SDs are given in Tables 22(a) and 27.

In both the Forces and civilian samples mean fat content rose with age, and the only differences significant at the 95% level between the 2 population samples were within the 40-44y and 45-49y groups, where the Forces means were about 1% fat higher. The increase with age was not completely smooth, as 2 marked increases, significant at the 99% level, occurred between late 20's-early 30's, and around late 30's-early 40's. As explained in the methods section however, these jumps probably reflect methodological artifacts although the general increase in fat content with age is still true.

For comparative purposes between the different age groups, the mean % fat ± 1 SD of the 17-19y men - i.e. 11-19% fat - was taken as a range of fat contents which might possibly represent an acceptable level. In fact this assumption needs modification, as will be discussed a little later in this section.

However, within each age group the percent of subjects above and below this range was calculated and these are shown in Table 57.

Table 57

Percent of Each Sample in Each Age Group, with Fat Contents over 19% and under 11%

Fat Content		16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	≥ 50
%<11% Fat	F	23	12.5	10.5	7.5	0.1	0.3	0	0	0
	C	-	11.9	8.3	7.6	0	0.01	0	0	0
%>19% Fat	F	6.5	18.5	30	36	68	68	87	93	91
	C	-	9.5	15.2	33.5	62.1	75	84	89	90

In total, about 42% of the Forces and 62% of the civilian sample were over 19% fat and most of these individuals were in the older age groups. The higher percent in the civilian sample reflected the fact that 33% of that sample were over 45y old compared with only about 4% of the Forces sample.

There were few differences between the 2 samples above about 25y, but between 17 and 24y almost twice the proportion of Forces compared to civilians, were over 19% fat. A sharp increase from about 18% to 30% of the age group occurred in the Forces sample, between 17-19y and 20-24y. A similiar jump, from approximately 15% to 33%, occurred in the civilians but between the age groups 20-24y and 25-29y i.e. on average 5 years later. Thereafter, both samples showed a sharp increase to about 70% by the early 30's and to almost 90% in the 40y olds. If this value of 19% fat were considered to be approximately the top end of a 'desirable' range in all age groups, this suggests that about 90% of the over 40's in both the civilian and Forces samples were 'overfat'.

Approximately 8% of the Forces and 3% of the civilians had fat contents below 11% and again this low proportion in civilians was due to the higher proportion of older subjects in this sample. All but 5 of these thin individuals were younger than 30y. Many of those over 30y old however, had low weights relative to their height and therefore beyond 30y in particular, low proportionate weight does not necessarily relate to a low fat content.

In an attempt to decide on the maximum fat content which could be classed as 'desirable', the exercise habits of the two samples were examined, and are shown in Table 51, Section 3.2.10. The methods chapter included a description of how this data was collected.

The American National Centre for Health Statistics (1974) measuring the triceps skinfold, and Tanner (1974) taking radiographic measurements have both found that as adolescents grow, their subcutaneous fat and overall fat content is also in a state of flux.

It is likely that 16-19y old males in this study were still growing (Tanner, 1966) and therefore although this was the most active group it is suggested that their fat contents should not be taken as 'desirable' for the entire male age range. The 20-24y olds on the other hand were fairly active, healthy young men most of whom would have reached their maximum growth and therefore their more stable mean fat content could act as an indicator to the maximum 'desirable' or 'permitted' level.

Apart from the 16-19y olds, these 20-24y olds were the most active in their spare time, with 66% and 57% of the Forces and civilians respectively exercising twice a week or more. It was apparent however that exercise was not the only factor involved in determining fat content, since within the 2 activity groups, mean fat content still increased with age.

The mean fat content of about 16% of body mass in this age group, was about the same as that found by Katch and McArdle (1973) in men of 19.3 $\pm$ 1.5y and Wilmore and Behnke (1968) in men aged 22.7 $\pm$ 3.7y and was approximately 3% above the values of 2 British studies by Haisman (1970) on soldiers aged 22.6 $\pm$ 2.2y and by Durnin and Rahaman (1967) on young adults aged 22.0 $\pm$ 3.2y. These comparisons suggest that the mean fat content in healthy young men living in a 'developed' country is indeed around 13-16% of body weight.

Returning to the original problem, it is very difficult in any study to determine what a 'desirable' maximum for body fat is, especially when a large age range is concerned. It is suggested in this study, that the mean percent fat plus 1SD in the 20-24y olds, physically mature men, may be a justifiable maximum since this group has been shown to me mainly healthy, active young men in an apparently stable state of body weight and composition. This would represent a maximum of approximately 20% fat.

It has generally been accepted when using the Quetelet Index, Weight for Height tables, or any other method for assessing 'desirable' weight, that little if any account or allowance should be made for age. This report may appear to differ slightly on that issue.

A phenomenon described by some workers (Skerlj, Brozek and Hunt, 1953; Durnin and Womersley, 1974) is that with increasing age an increasing proportion of the body's fat may become internal, as opposed to subcutaneous. In addition, skinfold compressibility appears to vary with age but the direction of the change and the effects have not been adequately described or quantified. While Durnin and Womersley (1974) suggested from their data that compressibility may increase with age, they also quoted many other studies which showed the converse. Hammond (1955) in studying children, found the compressibility to be 42%-43%, Garn (1956) and Garn and Gorman (1956) quoted 30-35% in 21-22y old men and Brozek and Mori (1958) reported 16% in 56-62y old men. All these studies used x-radiography as their standard against which to compare the skinfold measurements and Brozek and Kinsey (1960) suggested that the decrease in compressibility could be reflecting a general decrease in the water content of the tissues measured. Since it has been suggested that skinfold compressibility may increase with skinfold thickness, Womersley (1974) suggested that the apparent increase in compressibility with age found in his subjects, may have been due to the increase in skinfold thickness with increasing age.

These changes, together with possible changes in FFM composition, have the result that any one value for the sum of the four skinfolds, represents increasing fat proportions as age increases. A value of 35mm in a 19y old and in a 45y old would give them fat contents of approximately 15% and 20% respectively. If a 45y old was also 15% fat, his sum of the four skinfolds would be approximately only 25mm. As a result, it was noted throughout the field work that males over about 45y with fat contents which were average in the younger age groups i.e. 16%, had the appearance of being far leaner than younger individuals with the same fat content. Subjectively, a 45y old with 20% of his weight as fat, still seemed of 'normal' fatness.

These factors, together with the findings of the Chicago Gas Company study and various others mentioned in Chapter 1 raise the question: Should any age allowance be made when estimating the maximum 'desirable' fat content?

The answer to this question would appear to depend on the reasons behind the need to define this maximum: i.e. is the principal requirement that the maximum should represent a level below which most individuals are unlikely to develop weight related diseases? Must the individual also have the capacity to cope with physical stress such as sport or work related exercise? Within the Forces both these reasons are likely to be valid but it must be remembered that individual variation is high and there is no single fat content above which all the possible ills of 'overweight' suddenly become apparent.

On the relationship between fat content and disease there is not much hard evidence and the evidence which does exist tends to be controversial. As described in the Introduction, Chapter 1, it has generally been 'overweight' and not 'overfat' which has been related to mortality and morbidity and Van Itallie (1979), Keys (1980) and many others have pointed out that the relationships are neither obvious nor simple. The general conclusion which can be drawn from the data however appears to be that a small degree of 'overfat' makes little difference to health and there is no single optimum fat content. There also appears to be an age factor involved and it is possible that there are greater risks for young 'overfat' individuals than for older 'overfat' individuals. Moderate degrees of obesity aquired between the ages of 20 and 40y appears to be more detrimental to health than obesity developed in later life although it may have a long latent period (Van Itallie, 1979).

The relationship between fat content and 'fitness' or ability to carry out physical work and exercise is also far from simple. It is easily possible for an individual to be 'overfat' and more fit than a lean individual. In these circumstances however, unless the 'overfat' individual is involved in a sport or occupation where excess weight is useful, such as shot putting or lumberjacking, he would be even more fit if he did not have the excess fat to burden him. The conclusion once again is that no single fat content exists which is a critical demarcation in relation to fitness. Any reference point taken for purposes of such demarcation is essentially an approximation which is useful in a general sense but will have exceptions.

The net result of this discussion is that because of inconclusive research, individual variation, and the large number of other factors involved, only general guidelines for 'desirable' fat contents for <u>males</u> can be stipulated. We would suggest that across all the age groups between 16 and 30y of age a fat content of 20% should be taken as the maximum 'desirable' level. Because of the possible risks of obesity in the young, this maximum should be fairly strictly adhered to, especially at the youngest ages and a value of around 15% fat would be preferable.

Between 31 and 59y of age, 59y being the maximum age likely within the Services, a maximum of 25% fat would appear to be more applicable, with the more 'desirable' level being between 15-20% fat. (Obviously a 'jump' of 5% fat would not however be advisable between the ages of 30 and 31y.) The increase in 'desirable' fat content with age seems justified because (a) there appears to be less danger to health related to 'overweight' or 'overfat' in older individuals, (b) about 80% of the sample who were over 40y of age were also 20% fat or over and yet most exercised at least twice a week (c) almost no males aged 40-59y had fat contents of 15%, (d) a fat content of 25% in these older age groups would scarcely be considered obese. Again, the maximum limit of 25% fat should be more strictly adhered to in the age group between 31 and 40y, and a little leaway allowed in those over 50y of age.

These 'desirable' and maximum fat contents could also vary according to occupation: i.e. an infantryman versus a cook. Individuals who require to carry out hard exercise from time to time are better to be leaner than those who do not have these duties. However, this is clearly a matter for policy decisions which could over-ride these simple considerations.

It is suggested here that the same fatness levels should apply to both extremes of situations, because as they stand the levels are fairly flexible. The skinfolds method is not sufficiently accurate, and the hazards of fat not sufficiently large to justify instructing a fit, 25yr old infanteer to loose weight in order to go from 20% to 15% fat. A cook however still has a requirement to be healthy and since the incidence of obesity is related to mortality and morbidity he must not be permitted to become 'overfat'.

For these general reasons it is believed that the 2 maximum level of 20% and 25% fat for young and older men are valid for all occupations. It should be remembered however that these figures are only good guidelines and that a few pounds of fat either way are of little consequence.

3.3.2. Females

The mean fat content within 9 age groups and for both samples is shown in Table 58.

Table 58

Mean Fat Content in Each Age Group

Age (y)	16	17-19	20-24	25-29	30-34	35-39	40-44	45-49	≥50
Forces % Fat	-	28	28.1	27.1	29.7	30.6	34.0	31.1	35.7
Civilian % Fat	25	25.2	26.4	26.2	28.3	29.1	32.2	33.0	35.7

Forces n = 1086 Civilian n = 1170

In both samples, mean fat content increased with age from about 25% in the 16y old civilians to 36% in the over 50y olds. Between 17y and 24y however, the mean fat content in the Forces sample was significantly greater at the 99.9% level than the civilian fat content within the same age range. Overall, the increase in percent fat was fairly constant throughout the age groups although there was a slight 'jump' between the late 30's-early 40's, and late 40's-50's. As described in the Methods section however, these 'jumps' were probably methodological but the general trend was still true. By the age of about 19y most young females would have reached their maximum height and age related growth. Within the 20-24y group it would be expected therefore that all the females were physically mature.

In a similar manner to the male analysis, the exercise habits of the females were examined in order to help decide upon a maximum percent fat which could be classed as 'desirable'. These results are shown in Table 59.

Table 59

Exercise Habits of the Female Forces and Civilian Samples

Age (y)		16**	17-19	20-24	25-29	30-34	*35-39	*40-44	**45-49	** 50
EX 1	F	-	42	40	38	34	64	31	-	-
	C	-	29	31	30	31	27	27	21	22
EX 2	F	-	58	60	62	66	36	69	-	-
	C	-	71	69	70	69	73	73	79	78

Key: EX 1: Exercise ≥twice a week F = Forces n = 1083
Ex 2: Exercise <twice a week C = Civilian n = 1115

The results are expressed in terms of the percent of each age group, in each sample, which exercised at that level. The discrepancy between these values of n and those quoted earlier were due to some individuals not answering the question fully.

* Forces n<15 ** Forces n<6

Because of a low sample size, there was no worthwhile information on the 16y olds activity, and little of value beyond 34y in the Forces sample. Between 17 and 34y, unlike the male results there was little change in the activity patterns of either sample, with about 40% and 30% of the Forces and civilians respectively exercising twice a week or more, in their spare time. Since this compares with values of 75% and 65% in the male 17-19y olds and 51% and 45% in the 30-34y olds it suggests that these females could not be considered to lead very active lives in terms of physical exercise and therefore, that activity patterns cannot be used to help indicate the maximum 'desirable' fat content. The relationship between activity and fat content in females is in any case not at all clear cut.

The Forces between 17 and 24y old were on average fatter than their civilian equivalents, despite the fact that they appeared to be more active. This may be a by-product of their institutionalised eating habits which on the whole are more geared towards catering for active males than sedentary females.

Returning to a possible 'maximum' fat content for the females, a comparison was made between the results of this study and those of other workers. Previous studies on young women have found fat content ranges as shown in Table 60.

Table 60

Mean Fat Content of Young Women from Various Studies

Author	Mean Age (y)	Mean % Fat	Methodology
Pollock et al (1975)	20.2 ± 1.2	24.8 ± 6.4	Densitometry
Durnin and Rahaman (1967)	21.7 ± 3.2	24.2 ± 6.5	Densitometry
Katch and McArdle (1973)	20.3 ± 1.8	25.6 ± 6.4	Densitometry
Brown and Jones* (1977)	19-24	V. Active 22.1 ± 7.0 Active 22.3 ± 6.7 Sedentary 28.1 ± 6.8	Densitometry

* V. Active: estimated 10h activity/week
Active: estimated 4-8h activity/week
Sedentary: estimated 3h activity/week

From these results, it was concluded that although the 20-24y olds in this survey were fairly healthy young women, their mean fat contents of 26.4% and 28.1% were probably higher than the 'desirable' level and a 'desirable' level of approximately 24% would be better. As pointed out in the male analysis however, no single fat content is 'desirable' and a range is always more applicable. Since it is most unlikely that all the females studied in the work quoted in Table 60 were within a 'desirable' range of fat contents, it is suggested that 1SD above the mean could be taken as the maximum 'desirable' fat content, and this gives a value of approximately 30% fat.

Within the age range 16 to 34y it is therefore suggested that 30% fat should be taken as the maximum 'desirable' fat content in females and 24% be taken on average as a more advisable level. As in the male analysis, once again this maximum ought to be more stictly adhered to in the young age groups and a little leaway allowed among the older groups since a small degree of excess fat is not considered harmful.

Beyond 34y of age there is not sufficient data from this study or others to know exactly what the maximum 'desirable' level should be. On examining the female civilian results and using the same logic used in the male analysis however, a maximum of 35% fat could be suggested, together with a more advisable level of 30% fat. As mentioned previously however, this is only a guideline and the younger age groups should be kept to the lower end of the 'desirable' levels.

3.4. PREDICTION EQUATIONS FROM THE FORCES SAMPLE

3.4.1. Correlations Between the Variables, Related to Prediction Equations

The correlation coefficients, R, were calculated between all the measured and calculated anthropometric variables for both male and female Forces samples and are shown on Tables 61(a) and (b). An examination of these variables was carried out to assess the possible independent variables when percent fat or FFM were the dependent variables in regression equations.

Correlations

Forces Males 16-56 yrs (n = 5294)

Table 61(a)

	Age	Ht	Wt	% F	FFM	Log (wt)	Ulnar D	Tibia	Biac	Bi-il	Arm C	Thigh	Butt	Calf
Age	1													
Height	0.007	1												
Weight	0.34	0.51	1											
Perc. fat	0.59	0.04	0.69	1										
FFM	0.14	0.66	0.90	0.32	1									
Log (wt)	0.35	0.52	0.99	0.69	0.90	1								
Ulnar D	0.20	0.53	0.48	0.13	0.56	0.49	1							
Tibial D	0.08	0.54	0.68	0.32	0.71	0.68	0.63	1						
Biacr. D	0.16	0.54	0.57	0.22	0.63	0.58	0.43	0.45	1					
Biiliac D	0.34	0.53	0.63	0.38	0.60	0.63	0.46	0.52	0.48	1				
Arm C	0.41	0.16	0.85	0.74	0.68	0.89	0.32	0.47	0.39	0.42	1			
Thigh C	0.20	0.29	0.88	0.67	0.77	0.88	0.30	0.58	0.41	0.44	0.83	1		
Butt C	0.35	0.41	0.94	0.72	0.81	0.94	0.41	0.64	0.50	0.61	0.82	0.89	1	
Calf C	0.14	0.30	0.80	0.49	0.76	0.80	0.36	0.60	0.42	0.41	0.71	0.80	0.77	1

Correlations

Forces Females 17-35 yrs (n = 1047)

Table 61(b)

	Age	Ht	Wt	% F	FFM	Log (wt)	Ulnar D	Tibia	Biac	Bi-il	Arm C	Thigh	Butt	Calf
Age	1													
Height	-0.02	1												
Weight	0.01	0.53	1											
Perc. fat	0.02	0.03	0.66	1										
FFM	-0.01	0.67	0.90	0.27	1									
Log (wt)	0.00	0.54	0.99	0.66	0.90	1								
Ulnar D	0.03	0.51	0.39	0.01	0.51	0.40	1							
Tibial D	-0.03	0.43	0.74	0.46	0.69	0.75	0.48	1						
Biacr. D	0.04	0.54	0.50	0.13	0.58	0.51	0.41	0.36	1					
Biiliac D	0.16	0.48	0.55	0.29	0.53	0.55	0.32	0.45	0.40	1				
Arm C	0.01	0.11	0.79	0.78	0.57	0.70	0.19	0.58	0.24	0.33	1			
Thigh C	-0.01	0.27	0.87	0.69	0.73	0.88	0.23	0.70	0.32	0.41	0.81	1		
Butt C	0.03	0.40	0.90	0.67	0.78	0.90	0.30	0.71	0.40	0.52	0.76	0.91	1	
Calf C	-0.08	0.29	0.78	0.49	0.72	0.78	0.31	0.70	0.35	0.32	0.67	0.78	0.75	1

Males

Table 61(a) shows correlations ranging from 0.007 between age and height and 0.99 between weight and log (weight), but only those figures which affect the prediction of FFM and percent fat are discussed here.

The 3 variables correlating most highly with percent fat were the upper arm circumference, buttock circumference and log (weight) or weight, with values of R ranging from 0.74 to 0.69. Since weight and buttock circumference correlated more highly with FFM than percent fat however, they may not be the best choice for predicting fat. In addition the correlation between these two variables was high, 0.94, indicating that good predictive information would be gained from using either one and there would be no need for both. The variable 'age' correlated more highly with percent fat than with any other variable showing an R value of 0.59 and it therefore was also probably an important independent variable. Which variable could be used as a fourth predictor variable if required, would depend on how much information these first 3 could supply and would possibly be a bone measurement, (since this might supply some estimate of 'build') not highly correlated with the variables previously mentioned.

The 3 variables correlated most highly with FFM were log (weight) or weight together with the buttocks and thigh circumferences, with R values from 0.90 to 0.77. Once again weight and buttocks circumference also correlated well with percent fat, but FFM and weight were much more highly related than percent fat and weight with R values of 0.90 and 0.69 respectively. Buttocks circumference related to FFM and percent fat showed R values of 0.81 and 0.72 respectively which are quite similar. Its high correlation with weight of 0.94 would support the idea that again both buttock circumference and weight would not be required within one regression equation.

The relatively high correlation of 0.88 between weight and thigh circumference could possibly also reduce the value of thigh circumference as an independent variable for FFM if weight was also used. Other possible independent variables would be the calf circumference and tibial diameter because they correlated fairly highly with FFM but not too highly with percent fat. They did however also correlate fairly highly with weight.

The actual choice of the independent variables to predict percent fat or FFM was made by the computer program BMDP2R, which took into account not only the correlations with the dependent variable but also the inter-correlations between the predictor variables.

Females

The females demonstrated correlations from 0.003 for log (weight) and age, to 0.99 for weight and log (weight) but again only those figures affecting the prediction of percent fat or FFM are discussed here. Table 61(b).

The 3 variables which correlated most highly with percent fat were upper arm circumference, thigh circumference and buttock circumference, with R values ranging from 0.78 to 0.67. The 1st and 3rd variables were also among the 'best' 3 in the male sample but the female R values tended to be slightly lower. Again in a similar fashion to the male analysis, since the thigh and buttock circumferences correlated highly with each other and also better with FFM than percent fat, it was unlikely that both would be chosen by the program BMDP2R as suitable independent variables. Weight with a correlation of 0.66 might be chosen instead.

The variables weight or log (weight), buttock and thigh circumference showed the highest individual correlations with FFM, and R ranged from 0.90 to 0.73. All these variables correlated better with FFM than percent fat, but again it was unlikely that both buttock and thigh circumference would be of value in a prediction equation. A possible replacement would be the calf circumference or ulnar diameter. The variable 'age' showed no correlation greater than 0.16 with any other variable in the female sample, suggesting that there would be fewer age groups in the female sample than in the male sample, since there were fewer age related variations in the variables

Overall, the tables of correlations can only give an indication of the likely independent variables when predicting percent fat or FFM. The inter-correlations between independent and dependent variables complicate the situation; i.e. a variable such as ulnar diameter could prove to be a good independent variable for FFM because even though the R value was only 0.56 in the males and 0.51 in the females, it correlated poorly with percent fat and with the other likely independent variables.

The following sections describe how the independent variables were actually chosen.

3.4.2. Forces Males

(a) Predicting FFM: Choosing the 'Best' Independent Variables

Stepwise multiple regression analysis, (Programmes BMDP1R and BMDP2R) was carried out on the male Forces sample in order to predict FFM using independent variables selected from age, height, weight, the four limb circumferences, the four bone diameters and all their log transformations. Logs were used because many of the frequency distributions of the variables were not normal curves but tended to be positively skewed. Age^2 and age^3 were also used as possible independent variables, since the relationship between age and FFM was not linear, but slightly quadratic in form.

The subjects were initially divided into seven age groups and the regression analysis carried out on each group. Programme BMDP2R entered the independent variables one at a time into the regression equation, choosing at each step the variable which improved the predictive accuracy of the equation most. Table 62 shows these results and demonstrates that there was little advantage in increasing the number of independent variables over 3, since thereafter the addition of further variables, up to 7 in this case, did not increase R by more then 0.01 or reduce the Standard Error of the Estimate (SE_E) by more than 0.17kg in any group.

Within these age groups the 'best' 3 independent variables were height, log (weight) or weight, and ulnar diameter, except in the 25-29y group where calf circumference was better than ulnar. When no age grouping was used, the 'best' 4 independent variables were height, log (weight), ulnar diameter and age^3 - Table 63.

Forces Males: Predicting Fat Free Mass using the "Best" 3, 4 and 7 Independent Variables plus Age

Table 62

	"Best" 3 Variables			"Best" 4 Variables			"Best" 7 Variables		
AGE (yrs)	VARIABLES	R	SE_E	VARIABLES	R	SE_E	VARIABLES	R	SE_E
16 yrs (n = 363)	Height Ulnar D Log (wt)	0.96	1.55	plus Upperarm C	0.96	1.51	plus Calf C Biacromial D Log (Thigh C)	0.97	1.47
17-19 yrs (n = 1048)	Height Ulnar D Log (wt)	0.96	1.75	plus Thigh C	0.96	1.71	plus Calf C Upperarm C Biacromial D	0.96	1.66
20-24 yrs (n = 1266)	Height Ulnar D Log (wt)	0.95	2.03	plus Biacromial D	0.95	1.98	plus Calf C Thigh C Upper Arm C	0.95	1.91
25-29 yrs (n = 790)	Height Weight Calf	0.96	2.06	plus Ulnar D	0.96	1.96	plus Buttock C Biacromial D Upper Arm C	0.96	1.90
30-39 yrs (n = 1355)	Height Weight Ulnar D	0.96	1.76	plus Calf C	0.96	1.72	plus Buttock C Biacromial D Upper Arm	0.97	1.65
40-49 yrs (n = 406)	Height Weight Ulnar D	0.93	2.27	plus Calf C	0.93	2.20	plus Buttock C Biacromial D Tibial D	0.94	2.10
>50 yrs (n = 66)	Height Log (wt) Ulnar D	0.94	2.27	addition of more variables is of no value					

SE_E = Standard Error of the Estimate

Table 63

Males: Predicting FFM with 4 Independent Variables

Age (y)	Independent Variables	FFM (kg)	R	SE estimate
16-59y (n=5294)	Height Ulnar D Log (weight) Age^3	59.6 ±6.7	0.95	2.05kg
16-59y (n=5294)	Height Calf C Log (weight) Age^3	59.6 ±6.7	0.95	2.09kg

Since calf circumference is easier to measure than ulnar diameter which requires a special bone vernier, it would be more convenient in practical terms to replace ulnar diameter in all the equations with calf circumference. In choosing independent variables common to all the age groups log (weight) was preferable to weight since it was the better variable when no grouping was used. Equations were therefore calculated for each group using height, calf circumference and log (weight) as independent variables for predicting FFM. For each equation R and SE_E were also calculated and compared with those from the equations using the 'best' 3 variables chosen by the computer. These results are shown in Tables 64.

The slightly higher values for the SE_E in the equations which included calf, indicated a slight loss of accuracy. In all except the 50y group, however, this increase was <6% of the SE_E, or 0.1kg. It was, therefore, concluded that when the subjects were analysed either in age groups or as one group, height, log (weight) and calf circumference were the most practical and accurate independent variables from the selection measured, for predicting FFM.

(b) Predicting Fat Percent: Choosing the 'Best' Independent Variables

Forces Males: Predicting FFM in Age Groups, using 3 Independent Variables

Table 64

AGE (yrs)	INDEPENDENT VARIABLES	R	SE_E	INDEPENDENT VARIABLES	R	SE_E
16 yrs (n = 363)	Height Ulnar D Log (weight)	0.96	1.55	Height Calf C Log (weight)	0.96	1.60
17-19 yrs (n = 1048)	Height Ulnar D Log (weight)	0.96	1.75	Height Calf C Log (weight)	0.95	1.85
20-24 yrs (n = 1266)	Height Ulnar D Log (weight)	0.95	2.03	Height Calf C Log (weight)	0.94	2.11
25-29 yrs (n = 790)	Height Weight Calf C	0.96	2.06	Height Calf C Log (weight)	0.95	2.13
30-39 yrs (n = 1355)	Height Weight Ulnar D	0.96	1.76	Height Calf C Log (weight)	0.96	1.87
40-49 yrs (n = 406)	Height Weight Ulnar D	0.93	2.27	Height Calf C Log (weight)	0.93	2.33
≥ 50 yrs (n = 66)	Height Ulnar Log (weight)	0.94	2.27	Height Calf C Log (weight)	0.93	2.5

SE_E = Standard Error of the Estimate

Stepwise multiple regression was next used to predict percent fat, using the same variables and methods as before. When no grouping was used, the 'best' 4 independent variables were thigh circumference, upper arm circumference, ulnar diameter and age^3. Again, however, ulnar diameter is a relatively inconvenient measurement, and the next 'best' variable to replace it was height. This replacement only increased the SE_E by 3% from 2.76 to 2.84% when all ages were taken together and was therefore considered to be acceptable. Table 65.

Within age groups 3 independent variables again provided most of the information, and the largest reduction in SE_E when 7 were used was in the 25-29yr group, where it dropped by 12% from 2.91 to 2.54% of body weight. Table 66.

Between the age groups, the 'best' 3 predictor variables varied, but 3 common to all the groups had to be chosen. Ulnar diameter could be replaced by height, as explained above, and upper arm circumference was common to most groups. The 3rd variable in each group was thigh or buttock circumference. Table 65 shows the result when each of these two variables was used separately in the prediction equation but no age division was made. Since the SE_E was lower when buttock circumference was used as opposed to thigh circumference, this was taken as the better independent variable. When predictions were made for each age group, buttock circumference was still slightly more accurate for predicting FFM than thigh circumference. Table 66

Excluding the over 50y age group due to its relatively low value for n (n=66). Table 67 shows that when the subjects were put into age groups using height, buttock circumference and upper arm circumference as the 3 independent variables, as opposed to the 3 'best' variables chosen by the regression programme, SE_E increased by a maximum of only 5% or 0.12kg of body weight.

It was, therefore concluded that these 3 independent variables were the most useful, common to all age groups, for predicting fat percent.

Males: Predicting Fat Percent with 4 Independent Variables

AGE (yrs)	INDEPENDENT VARIABLES	% FAT	R	SE_E
16-59 yrs (n = 5294)	Thigh Upperarm C Ulnar Age^3	18.15 ± 5.3	0.84	2.76%
16-59 yrs (n = 5294)	Height Buttock C Upperarm C Age^3	18.15 ±5.3	0.85	2.79
16-59 yrs (n = 5294)	Height Thigh C Upperarm C Age^3	18.15 ±5.3	0.84	2.84

Forces Males: Predicting Percent Fat, using the "Best" 3, 4 and 7 Independant Variables plus Age **Table 66**

AGE (yrs)	"Best" 3 Variables			"Best" 4 Variables			"Best" 7 Variables		
	VARIABLES	R	SE_E	VARIABLES	R	SE_E	VARIABLES	R	SE_E
16 yrs (n = 363)	Thigh Upper Arm C Ulnar D	0.72	2.19	plus Log (calf) C	0.73	2.18	plus Biiliac D Log (Buttock) C *	0.74	2.15
17-19 yrs (n = 1048)	Thigh C Upper Arm C Ulnar D	0.81	2.40	plus Buttock C	0.81	2.37	plus Weight Log (Calf) C Log (Biiliac) D	0.82	2.32
20-24 yrs (n = 1260)	Thigh C Upperarm C Ulnar D	0.81	2.76	plus Log (Buttock C)	0.81	2.71	plus Log (wt) Calf C Biacrom D	0.83	2.60
25-29 yrs (n = 790)	Thigh C Upperarm C Ulnar D	0.77	2.91	plus Log (Buttock C)	0.79	2.8	plus Height Log (wt) Calf C	0.83	2.54
30-39 yrs (n = 1355)	Log (Arm C) Log (Ulnar D) Log (Butt C)	0.79	2.31	plus Height	0.79	2.28	plus Calf C Biacrom D Log (wt)	0.81	2.17
40-49 yrs (n = 406)	Height Log (Butt C) Log (wt)	0.75	2.99	plus Calf C	0.77	2.88	plus Log (Biiliac D) Log (Tibial D) Ulnar D	0.79	2.74
≥ 50 yrs (n = 66)	Height Weight Log (Ulnar D)	0.84	2.85	addition of more variables is of no value					

SE = Standard Error of the Estimate

*Addition of further variables did not improve the regression & were therefore not entered into the equation by program BMDP2R

Forces Males: Predicting Fat % in Age Groups, using 3 Independent Variables

Table 67

AGE (yrs)	3 "Best" INDEPENDENT VARIABLES	R	SE_E	INDEPENDENT VARIABLES	R	SE_E
16 yrs (n = 363)	Thigh Upper Arm C Ulnar D	0.72	2.19	Height Buttock C Upper Arm C	0.69	2.30
17-19 yrs (n = 1048)	Thigh Upper Arm C Ulnar D	0.81	2.40	Height Buttock C Upper Arm C	0.78	2.52
20-24 yrs (n = 1260)	Thigh Upper Arm C Ulnar D	0.81	2.76	Height Buttock C Upper Arm C	0.79	2.82
25-29 yrs (n = 790)	Thigh C Upper Arm C Ulnar D	0.77	2.91	Height Buttock C Upper Arm C	0.77	2.90
30-39 yrs (n = 1355)	Log (Arm C) Log (Ulnar D) Log (Buttock C)	0.79	2.31	Height Buttock C Upper Arm C	0.77	2.42
40-49 yrs (n = 406)	Height Log (Buttock C) Log (Weight)	0.75	2.99	Height Buttock C Upper Arm C	0.73	3.1
≥ 50 yrs (n = 66)	Height Weight Log (Ulnar)	0.84	2.85	Height Buttock C Upper Arm C	0.79	3.34

SE_E = Standard Error of the Estimate

3.4.3. Division of the Male Subjects into Groups

Harrington (1963) and Goldstein (1980) both indicated that if possible any sample should be split into sub-samples, as an over-all regression may be misleading. Goldstein (1980) also stated that the number of sub-groups must depend on the size and stability of the differences between the groups, together with convenience and cost.

For the sake of simplicity and practicality, any grouping variable chosen in this analysis must be easily measured and easily categorised. The obvious choices are therefore, height, weight and age, as most people could put themselves into these groups fairly easily. For simplicity's sake, it would also be preferable to use only 1 grouping variable, and use the others as independent, continuous variables if required. In this section the most accurate grouping variables for predicting FFM and percent fat were chosen.

From the previous section, the most practicable and accurate variables for the prediction of FFM and percent fat were found to be (height, log (weight), calf and age) and (height, upper arm circumference, buttock circumference, age) respectively.

The value of R varied greatly between the groups and was mainly influenced by the variability in FFM and percent fat within each group. A better statistic to compare is therefore the SE_E.

In weight groups, Tables 68 and 69, the ranges for SE_E were (1.8-3.37)kg and (2.32-3.00)% for predicting FFM and percent fat respectively. In height groups, the ranges were (1.74-2.5)kg and (2.63-2.89)% for FFM and percent fat respectively, and in age groups (1.60-2.5)kg and (2.30-3.34)% respectively. Only groups with values of $n \geqslant 30$ were taken into consideration. There was no obvious 'best' grouping from these results since the SE_Es were all fairly similar.

If the SE_E in each individual group, was compared to the SD of the dependent variable in that group, and the ratio of SE_E: SD calculated, it would be expected that the better the prediction, the lower the ratio. Table 70. Looking at this figure, the best set of predictions for FFM was in age groups, and for percent fat, was in height groups. Overall, the

Males: Prediction of FFM - Subjects divided into Weight Groups and Height Groups   Table 68

Weight Grouping	Independant Variables	R	SE_E	Height Grouping	Independant Variables	R	SE_E
≤ 60 kg (n = 497)	Height Calf Age3	0.66	2.01	≤ 165 cm (n = 279)	Calf Log (wt) Age3	0.93	1.74
60–65 kg (n = 703)	Height Calf Age3	0.64	1.80	165–170 cm (n = 737)	Calf Log (wt) Age3	0.91	1.89
65–70 kg (n = 1057)	Height Calf Age3	0.68	2.0	170–175 cm (n = 1419)	Calf Log (wt) Age3	0.92	2.04
70–75 kg (n = 944)	Height Calf Age3	0.71	2.18	175–180 cm (n = 1440)	Calf Log (wt) Age3	0.91	2.11
75–80 kg (n = 809)	Height Calf Age3	0.70	2.34	180–185 cm (n = 945)	Calf Log (wt) Age3	0.91	2.23
80–85 kg (n = 577)	Height Calf Age3	0.71	2.41	185–190 cm (n = 360)	Calf Log (wt) Age3	0.91	2.41
85–90 kg (n = 327)	Height Calf Age3	0.74	2.45	190–195 cm (n = 96)	Calf Log (wt) Age3	0.92	2.5
90–95 kg (n = 182)	Height Calf Age3	0.71	2.62	195–200cm (n = 15)	Calf Log (wt) Age3	0.98	1.27
> 95 kg (n = 197)	Height Calf Age3	0.73	3.37	> 200cm (n = 2)	Calf Lof (wt) Age3	–	–

SE_E = Standard Error of the Estimate

Males: Prediction of % Fat - Subjects divided into Weight Groups and Height Groups

Table 69

Weight Grouping	Independent Variables	R	SE_E	Height Grouping	Independent Variables	R	SE_E
< 60 kg (n = 497)	Height Buttock C Upperarm C Age[3]	0.61	2.32	< 165 cm	Buttock C Upperarm C Age[3]	0.87	2.63
60-65 kg (n = 703)	Height Buttock C Upperarm C Age[3]	0.67	2.60	165.1-170 cm	Buttock C Upperarm C Age[3]	0.85	2.80
65-70 kg (n = 1057)	Height Buttock C Upperarm C Age [3]	0.70	2.73	170.1-175 cm	Buttock C Upperarm C Age[3]	0.85	2.86
70-75 kg (n = 944)	Height ButtockC Upperarm C Age [3]	0.71	2.85	175.1-180 cm	Buttock C Upperarm C Age[3]	0.85	2.78
75-80 kg (n = 809)	Height Buttock C Upperarm C Age[3]	0.70	3.00	180.1-185 cm	Buttock C Upperarm C Age[3]	0.85	2.78
80-85 kg (n = 577)	Height Buttock C Upperarm C Age[3]	0.70	2.84	185.1-190 cm	Buttock C Upperarm C Age[3]	0.85	2.89
85-90 kg (n = 327)	Height Buttock C Upperarm C Age[3]	0.73	2.86	190.1-195 cm	Buttock C Upperarm C Age[3]	0.84	2.65
90-95 kg (n = 182)	Height Buttock C Upperarm C Age[3]	0.72	2.63	195.1-200 cm	Buttock C Upperarm C Age[3]	0.94	1.99
> 95 kg (n = 197)	Height Buttock C Upperarm C Age[3]	0.79	2.42	> 200 cm	Buttock C Upperarm C Age[3]	-	-

Males: Predicting FFM., % Fat – Ratio of $\frac{SE_E}{SD}$ within Weight, Height and Age Groups

Table 70

Predicting FFM (kg)						Predicting % Fat					
Weight Groups	$\frac{SE_E}{SD}$	Height Groups	$\frac{SE_E}{SD}$	Age Groups	$\frac{SE_E}{SD}$	Weight Groups	$\frac{SE_E}{SD}$	Height Groups	$\frac{SE_E}{SD}$	Age Groups	$\frac{SE_E}{SD}$
< 60 kg	0.74	165 cm	0.37	16–19	0.30	≤60 kg	0.80	165 cm	0.49	16–19	0.64
60.1–65	0.78	165.1–170	0.41	20–24	0.33	60.1–65	0.74	165.1–170	0.53	20–24	0.61
65.1–70	0.74	170.1–175	0.41	25–29	0.29	65.1–70	0.72	170.1–195	0.53	25–29	0.63
70.1–75	0.70	175.1–180	0.41	30–39	0.28	70.1–75	0.69	175.1–180	0.53	30–39	0.65
75.1–80	0.71	180.1–185	0.42	40–49	0.37	75.1–80	0.71	180.1–185	0.53	40–49	0.69
80.1–85	0.71	185.1–190	0.41	50	0.38	80.1–85	0.71	185–190	0.53	> 50 yrs	0.63
85.1–90	0.68	190.1–195	0.40	–	–	85.1–90	0.70	190.1–195	0.55	–	–
90.1–95	0.71	195.1–200	0.19	–	–	90.1–95	0.69	195.1–200	0.33	–	–
> 95 kg	0.69	> 200 cm	–	–	–	>95 kg	0.70	> 200 cm	–	–	

SE_E = Standard Error of the Estimate

lowest ratios were found when predicting FFM in age groups.

Using age, as opposed to height, groups had the added advantage that it is easier for an individual to put himself into an age group than a height group.

Predicting FFM as opposed to percent fat has the advantage that there is only one circumference, calf, to be measured, and it can be fairly easily measured by an individual on himself. Predicting percent fat requires both buttock and upper arm circumferences and the arm circumference is not very easily measured on oneself.

When the SE_Es from the prediction of percent fat were converted from percentages to kg at an average weight of about 70kg, they were approximately the same as their equivalent SE_Es following the prediction of FFM. At heavier weights however they were larger, and at lighter weights, smaller. Since one of the main aims of this project is to pinpoint obese and 'overfat' individuals and these individuals are more likely to be above average weight, then an error which increased with increasing weight was not desirable.

<u>Summary</u>

In summary, therefore, it was found that within this sample of Forces males between 16-59y, it was more accurate to predict FFM than percent fat and that this prediction should be made with the subjects divided into age groups. The best 3 independent variables were height, log (weight) and calf circumference.

3.4.4. Cutpoints for the Male Age Groups when Predicting FFM

It was demonstrated in the previous section, that when predicting FFM in age groups, the most practicable and accurate independent variables among those measured in this survey were height, log (weight) and calf circumference. The actual number of groups would be dependent upon the differences between the groups.

In order to decide into how many age groups the male sample ought to be divided, it was initially divided into 9 groups as this was considered to be the maximum feasible number. These groups are listed below:

1. 16 y
2. 17-19y
3. 20-24y
4. 25-29y
5. 30-34y
6. 35-39y
7. 40-44y
8. 45-49y
9. 50-56y

The regressions of FFM vs height, log (weight) and calf circumference was calculated for each group as explained in section 3.4.1.

These groups were then paired off with one then the other adjacent group, and with each pairing the regression equation was again calculated.

In order to combine two age groups, it had to be shown that using two independent prediction equations was no more accurate than using one for the groups combined i.e. that the residual error from the one group was much the same as the sum of the residual errors from the two individual groups.

This was tested by carrying out the F-test below:

$$F = \frac{(RSS_1 + RSS_2) - RSS_{Total} \quad /K}{RSS_{(1+2)}/df_{Total}}$$

<u>Key</u>

k = no of independent variables + 1

RSS_1 = Residual Sum of Squares from the regression on Group 1

RSS_2 = Residual Sum of Squares from the regression on Group 2

$RSS_{(1+2)} = RSS_1 + RSS_2$

RSS_{Total} = Residual Sum of Squares for the 2 groups combined

$DF_{Total} = (N_1 + N_2) - k$

N_1 = no in Group 1

N_2 = no in Group 2

F values were calculated as shown in Table 71. High values signified that the 2 age groups combined were significantly different from the two groups independently. Low values signified the opposite and that joining the groups was justified.

This test showed that the only groups which could be combined with little loss of accuracy were 30-34y with 35-39y and 40-44y with 45-49y. At the 95% level there was no significant difference between the accuracy of using the two independent regressions, as opposed to one regression for the two groups combined.

Table 71

AGE GROUP	16-19	17-24	20-29	25-34	30-39	35-44	40-49	45-56
'F' VALUE	7.2	9.7	6.6	110	2.3*	73	0.8*	4.7

* At the 95% level there was no significant difference between the 2 individual age groups and the 2 groups combined.

Regression equations were therefore calculated for seven age groups, and are listed in Table 72.

Table 72

Males: Equations for Predicting FFM in 7 Age Groups

16 y

FFM = (17 x Height) + (0.19 x Calf C) + (86.14 x log (weight)) - 136.91

17-19 y

FFM = (21 x Height) + (0.15 x Calf C) + (79.53 x log (weight)) - 131.69

20-24 y

FFM = (25 x Height) + (0.32 x Calf C) + (73.44 x log (weight)) - 132.57

<u>25-29 y</u>

FFM = (26 x Height) + (0.53 x Calf C) + (70.03 x log (weight)) - 135.67

<u>30-39 y</u>

FFM = (21 x Height) + (0.28 x Calf C) + (85.12 x log (weight)) - 148.03

<u>40-49 y</u>

FFM = (25 x Height) + (0.41 x Calf C) + (65.7 x log (weight)) - 125.70

<u>50-56 y</u>

FFM = (33 x Height) + (0.17 x Calf C) + (61.44 x log (weight)) - 122.44

<u>Units</u>

Height (m)	Weight (kg)
Calf (cm)	FFM (kg)

3.4.5. <u>Forces Females</u>

(a) Predicting FFM: Choosing the 'Best' Independent Variables

Stepwise Multiple Regression Analysis (Programmes BMDP1R and BMDP2R) was carried out on the female data in order to predict FFM using the same methodology as was used on the male sample. The independent variables were chosen from age, age^2, age^3, height, weight, 4 limb circumferences, 4 bone diameters and all their log transformations.

Since there were only 22 female subjects aged between 40y and 56y, only those under 40y i.e. 17-39y were included in the analysis.

The subjects were initially divided into 4 age groups and the regression analysis carried out on all the subjects. The results are shown on Table 73, and demonstrate that there was little advantage in increasing the

Forces Females: Predicting FFM in Age Groups, using the "Best" 3, 4 & 7 Independent Variables

Table 73

	"Best" 3 Variables			"Best" 4 Variables			"Best" 7 Variables		
AGE (yrs)	VARIABLES	R	SE_E	VARIABLES	R	SE_E	VARIABLES	R	SE_E
17-39 yrs (n = 1,054)	Weight Upper Arm C Ulnar D	0.94	1.60	plus Height	0.94	1.52	plus Calf C Log (Tibial) D Log (Biacromial) D	0.95	1.50
17-19 yrs (n = 403)	Weight Upper Arm C Height	0.95	1.44	plus Log (Calf) C	0.95	1.39	plus Ulnar D Tibial D Biacromial D	0.95	1.34
20-24 yrs (n = 483)	Weight Upper Arm C Ulnar D	0.94	1.62	plus Calf C	0.94	1.59	plus Height Biacromial D *	0.94	1.54
25-29 yrs (n = 117)	Weight Upper Arm C Ulnar D	0.94	1.72	plus Biacromial	0.94	1.68	plus *		
30-39 yrs (n = 51)	Height Weight Biiliac D	0.95	1.38	plus Log (Biacromial)D	0.96	1.29	*		

*Addition of further variables did not improve the regression and were not entered into the equation by program BMDP2R number of independent variables over 3, since thereafter the addition of up to 4 more variables did not increase R by more than 0.01 or reduce the SE_E by more than 0.1kg. R and SE_E values ranged from 0.94 to 0.95 and 1.38kg to 1.72kg respectively.

When the subjects were treated as one, the 'best' 3 independent variables were weight, upper arm circumference and ulnar diameter. It was noted the age, age^2 or age^3 were not among the 'best' 3 or even 7 available variables for predicting FFM. This suggested that possibly age grouping was not necessary for this female sample.

Within age groups, the 'best' 3 variables were weight, upper arm circumference and either ulnar diameter or height, except in the 30-39y group where weight, height and bi-iliac diameter were best. As explained in the male analysis, it would be more convenient to measure height than ulnar diameter. Table 74 shows the values of R and the SE_E when ulnar diameter then height were each used in turn together with weight and upper arm circumference as the 3rd independent variable. Replacing bi-iliac diameter with upper arm circumference in the 30-39y group only increased the SE_E from 1.38 to 1.44 and allowed the same independent variables to be used in all age groups. Within any age group, R did not vary by more than 0.01 or SE_E by more than 0.08 between the 2 sets equations. It was therefore, concluded that either height or ulnar diameter could be used in all the age groups with little loss of accuracy. Since height was the easier to measure, it was taken as the more suitable. The 3 most convenient and accurate variables for predicting the FFM of this female sample between the ages of 17-39y were therefore height, weight and upper arm circumference.

The 3 most suitable variables for predicting FFM in the male sample were height, log (weight) and calf circumference. Since it would simplify matters if these 3 variables could be used with the female sample also, with little loss of accuracy, programme BMDP1R was used to calculate the prediction equations with these variables. The results are also shown on Table 74. By comparing all these results it is seen that the SE_E in each group increased by on average about 0.14kg, or 9% and R decreased by a maximum of 0.03 in the 25-29y group. While this represents a definite loss in accuracy in each age group, because it is relatively small it could be

Forces Females: Predicting FFM in Age Groups, Using Different sets of Independent Variables

AGE (yrs)	FFM (kg)	INDEPENDENT VARIABLES	R	SE_E	INDEPENDENT VARIABLES	R	SE_E	INDEPENDENT VARIABLES	R	SE_E
17-19 yrs (n = 403)	43.4 ±4.5	Weight Upper Arm C Ulnar D	0.95	1.45	Weight Upper Arm C Height	0.95	1.44	Height Log (weight) Calf C	0.94	1.53
20-24 yrs (n = 483)	43.9 ±4.7	Weight Upper Arm C Ulnar D	0.94	1.62	Weight Upper Arm C Height	0.93	1.65	Height Log (weight) Calf C	0.93	1.74
25-29 yrs (n = 117)	44.0 ±5.1	Weight Upper Arm C Ulnar D	0.94	1.72	Weight Upper Arm C Height	0.94	1.80	Height Log (weight) Calf C	0.91	1.74
30-39 yrs (n = 51)	42.0 ±4.3	Weight Upper Arm C Ulnar D	0.94	1.49	Weight Upper Arm C Height	0.94	1.44	Height Log (weight) Calf C	0.94	1.47
17-35 yrs (n = 1,047)	43.6 ±4.7	Weight Upper Arm C Ulnar D	0.94	1.60	Weight Upper Arm C Height	0.94	1.61	Height Log (weight) Calf C	0.93	1.73

NOTE: Numbers of Females over 40 yrs were too small to carry out regression analysis.

considered acceptable it it was considered preferable to use the same independent variables in both the male and female samples, when predicting FFM. In most instances however, it is hypothesised that there would be no inconvenience in using different variables for the two sexes. The recommended variables were therefore still height, weight and upper arm circumference.

(b) Predicting Fat Percent: Choosing the 'Best' Independent Variables

Stepwise multiple regression (program BMDP2R) was used to predict percent fat using the same variables and methods as described previously. Results are shown in Table 75. Within age groups, in general there was again little point in increasing the number of independent variables over 3, because this resulted in only small improvements in R and SE_E. In the 30-39y group however, using 4 independent variables did increase R by 0.03 and reduce the SE_E by 0.14kg.

When no grouping was used, the 'best' four independent variables were ulnar diameter, log (buttock circumference) log (upper arm circumference) and calf circumference. Within age groups, the 'best' 3 variables varied, but included either ulnar diameter or height, plus log (buttock circumference) or log (weight) and finally either log (upper arm circumference) or bi-iliac diameter. The values for R and SE_E varied from 0.80 to 0.84 and 2.39% to 2.82% respectively. When converted into kgs, this range for the SE_E was similar to the range found when predicting FFM.

Since ulnar diameter is relatively inconvenient to measure, it would be again replaced by height. Log (upper arm circumference) would be favoured more than bi-iliac diameter since it was the better independent variable in 3 out of 4 age groups. For the 3rd variable log (weight) would be favoured more than log (buttock circumference) since it is easier to measure. These alterations led to the final choice of height, log (weight) and log (upper arm circumference) as the 3 most practicable variables for the prediction of percent fat. The resulting values for R and the SE_E are shown in Table 126. These are however also the 3 variables chosen for predicting FFM in this female sample.

It was therefore concluded by comparing Tables 74 and 76, that it was

Forces Females: Predicting % Fat in Age Groups, using the "Best" 3, 4 and 7 Independent Variables

Table 75

AGE (yrs)	"Best" 3 Variables VARIABLES	R	SE_E	"Best" 4 Variables VARIABLES	R	SE_E	"Best" 7 Variables VARIABLES	R	SE_E
17-39 (n = 1054)	Ulnar D L (Buttock C) L (Upp.Arm C)	0.81	2.60	plus Calf C	0.81	2.57	plus Height L (wt) L (Biacromial D)	0.83	2.46
17-19 (n = 403)	Ulnar D L (Buttock C) L (Upp.Arm C)	0.80	2.39	plus L (Calf C)	0.81	2.36	plus Height L (Tibial D) L (wt)	0.82	2.27
20-24 (n = 483)	Ulnar D L (Buttock C) L (Upp.Arm C)	0.83	2.58	plus Calf C	0.83	2.55	plus Height L (wt) L (Biacromial D)	0.84	2.46
25-29 (n = 117)	Ulnar D L(Upp.Arm C) L (wt)	0.84	2.82	plus Biacromial D	0.85	2.79	plus *		
30-39 (n = 51)	Height Biiliac D L(wt)	0.81	2.23	plus L (Biacromial D)	0.84	2.09	plus *		

* Addition of further variables did not improve the regression and they were therefore not entered into the equation by program BMDP2R

L = Logarithm

Forces Females: Predicting % Fat in Age Groups, using 3 Independent Variables

Table 76

AGE (yrs)	INDEPENDENT VARIABLES	R	SE_E	% FAT
17-19 yrs	Log (weight) Log (arm C) Height	0.80	2.40	28.0 ± 4.0
20-24 yrs	Log (weight) Log (arm C) Height	0.82	2.63	28.1 ± 4.6
25-29 yrs	Log (weight) Log (arm C) Height	0.82	2.30	27.1 ± 5.2
30-39 yrs	Log (weight) Log (arm C) Height	0.79	2.29	29.9 ± 3.7

prefereable to predict FFM than percent fat because within age groups, once the 3 most convenient and accurate independent variables were selected, the FFM prediction was more accurate. In addition, since FFM was the better dependent variable in the male sample it was more convenient to standardise the 2 sexes and also use this variable in the female sample.

Summary

In summary, it was found in this sample of Forces females between 17 and 39y, that it was more accurate and convenient to predict FFM than percent fat, and that this prediction could be made using the independent variables height, weight and upper arm circumference. The females were grouped according to their age as opposed to their height or weight, because this was the best grouping in the larger, male sample and it was desirable for the sake of simplicity, to standardise as much as possible the methodology used in the 2 sexes.

3.4.6. Cutpoints for the Female Age Groups when Predicting FFM

As explained in the male analysis section, the number of age groups into which the females had to be divided was dependent on the differences between the individual smallest groups. The females were therefore initially divided into the 7 age groups listed below:

1. 17-19y
2. 20-24y
3. 25-29y
4. 30-34y
5. 35-39y
6. 40-44y
7. 45-49y

The regressions of FFM vs height, weight and upper arm circumference were calculated for each group. These groups were then paired off with one, then the other, adjacent group, and with each pairing the regression equation was again calculated. If there was no significant loss of predictive accuracy when 2 groups were joined together, a third adjacent groups was also added on and the regression calculated.

In order to assess whether there was a significant loss of accuracy when age groups were joined together, an F-test, as described in the male analysis was calculated at each pairing of 2 groups. The significance was tested using F-tables and the results are shown in Table 77.

Table 77

Age Group	17-24	20-29	17-29	25-34	30-39	35-44	40-49
'F' Value	2.17*	1.25*	1.98*	119	0.25*	3.96	5.16

* At the 95% level there was no significant difference between the individual age groups and the groups combined.

These results showed that no significant differences existed between the groups 17-19y, 20-24y or 25-29y on one hand or 30-34y and 35-39y on the other hand. Regression equations were therefore calculated for only 2 age groups, 17-29y and 30-39y and these are described below. Because of low numbers, no equations were calculated for individuals over 40y. See Table 78

Table 78

Females: Equations for Predicting FFM in 2 Age Groups

17-29 y

FFM = (10.9 x Height) - (0.51 x Upper arm C) + (0.563 x Weight) + 5.6

30-39 y

FFM = (14.7 x Height) + (0.14 x Upper Arm C) + (0.397 x Weight) - 9.6

Units

Height (m)	Weight (kg)
Upper arm (cm)	FFM (kg)

3.4.7. The Use of Frame Categories in the Assessment of Fatness

When assessing an individual's 'desirable' or 'recommended' weight from a series of anthropometric measurements including height and weight, it is generally accepted that, where possible, skeletal size, muscularity, and general 'build' should be taken into account. In this way some differentiations can be made between the fat and FFM components of weight.

As a result of the American Build and Blood Pressure study, published in 1959 which related mortality to relative weight, the Metropolitan Life Insurance Company published in 1959 'New Weight Standards for Men and Women'. They took the average weights within the 20-24y age group measured in the Build and Blood Pressure survey and classed these as 'desirable' for all ages from 20y. Table 5. The Insurance Company appreciated that no single weight was 'desirable' for all individuals of the same height, because of the 'build' differences and therefore they divided the range of 'desirable' weights into 3 'frame' categories. In their 1959 report it was stated that the categories were produced from 'available anthropometric studies' but no further explanation was provided. It appeared as if the distribution of weights was in fact just divided into 3rds and labelled 'small', 'medium' and 'large' frame. The company did not state whether 'frame' was meant to represent skeletal dimensions alone or overall 'build'. Since the average range across all 3 'frame group' means was about 30lbs or 9kgs, and the average skeletal mass in a 75kg man is only about 12kgs, this suggests that some other variable apart from skeletal size was being taken into account. In any case, the company did not provide any method for measuring this ambiguous variable.

In this discussion 'frame' is used to refer to skeletal dimensions only but before discussing the results from this study, some other recent studies will be examined.

Frisancho and Flegel (1983) measured elbow and bitrochanteric breadth in 16,494 males and females of mixed ethnic origins between the ages of 18 and 74y and found that elbow breadth had the lowest correlation with adiposity as estimated from the triceps and subscapular skinfolds. In males R ranged from 0.18 to 0.28 and in females from 0.29 to 0.45. Within the male sample in our study with the age range from 16 to 56y the overall correlation of ulnar diameter with percent fat as estimated from 4 skinfolds was lower, at 0.13 which suggests that ulnar diameter may be a better indicator than elbow breadth of skeletal size. A comparison of R values without any SE_Es is not however always justified when different population samples are being considered.

Frisancho and Flegel then classified individuals into 3 'frame' categories according to their elbow breadth and also into 3 stature groups and found that the former categories were more useful than the latter in weight discrimination. They did not however appear to consider the value of age grouping, did not look at the height variability within each 'frame' group and did not quantify how their categories differentiated between fat and FFM.

Garn et al (1983) examined the roentgenogrammetric Bony Chest Breadth (BCB) as a measure of 'frame' size and divided their 2201 male subjects aged between 45 and 65yrs into 3 categories according to their BCB measurement. Their results showed that fatness as assessed from individual skinfolds did not vary substantially between the groups and although mean height increased from the 'small' to the 'large' frame group it did not increase sufficiently to account for the parallel weight increases. Correlations between any of the variables such as height and 'frame' were not however quoted and only a relatively small age range was examined. It therefore appears that BCB may be a useful indicator of FFM to be used in parallel with height, but more statistical information on a larger age range and using a better indicator of 'fatness' is required. It is however, unfortunately impractical in field studies to measure BCB because of the equipment required.

Katch and Freedson (1982) developed a slightly different approach to 'frame' size. They combined height, biacromial and bitrochanteric diameters into a frame size model named 'HAT' which was based on the relationship between height and the sum of the 2 bone diameters. This group had also measured bi-iliac, elbow, chest, wrist, knee and ankle diameters in their study group of 182 females and 113 males of average age 22y, but for some unexplained reason they did not include the last four in this 'frame' analysis. Their choice of the sum of biacromial and bitrochanteric diameters to indicate 'frame' was based on their low correlation with height (0.27 in males, 0.21 in females) and the relatively large measurement errors involved when measuring bi-iliac and chest diameters. Biacromial diameter alone however, had a lower correlation with height (0.08 in males, 0.12 in females) than the sum of the 2 diameters.

This system basically worked by putting individuals into one of 3 'frame' categories dependent on their height plus a small correction related to the sum of the biacromial and bitrochanteric diameters. The correction was actually very minor i.e. all the males over 186cm were large 'framed' and all below about 166cm were small 'framed' unless their 2 summed diameters exceeded about 100cm. Out of approximately 5300 male subjects in this present survey however, none had a biacromial diameter over 50cm and therefore it would be most unusual if the 2 diameters summed exceeded 100cm. 'Frame' was therefore mainly determined by height in this system and bone width was only of minor importance.

Another fault with this method was that suggestions were made which were unjustified due to the low sample variability. Percent fat, as estimated by densitometry and the equation of Siri, averaged $13.7 \pm 0.5\%$ in the male subjects and $24.5 \pm 0.5\%$ in the females. There was really very little variability. When the subjects were described within 'frame' groups however, the lack of any significant differences in percent fat between the groups was suggested as evidence. that the weight differences were due mainly to FFM differences. While this is true within this sample it is also inevitable since there was little variability in percent fat in the first case. Before these categories could be suggested as differentiating between weight related to fat or FFM, further analysis with subjects of more widely varying fat contents and also with a larger age range would be required. Since percent fat tends to increase with age, it is likely that an age factor would be required when using this type of 'frame' categorisation, as a single 'HAT' value would represent different fat contents in different age groups. Because of the relatively small contribution of the 'AT' component i.e. the 2 diameters to the classification of 'frame', its value in the first case is questionable.

The question therefore arose: Is there any justification in taking into account skeletal dimensions other than height when assessing 'fatness' or 'desirable' weight?

In order to examine this question, 4311 male Forces subjects between the ages of 16 and 56y were examined. On each subject the variables: height, weight, the circumferences at the calf, upper arm, buttocks and thigh sites, ulnar, tibial, biacromial and bi-iliac diameters plus biceps, triceps, subscapular and supra-iliac skinfolds were measured. From the 4 skinfolds and using the equations of Durnin and Womersley (1974) each individual's fat content and FFM were calculated.

Katch et al, (1982) stated that 'Frame' could be broadly described as bone size in relation to height. Frisancho et al (1983) on the other hand, examining data from the US Health and Nutrition Examination Survey (HANES 1) stated that 'Frame' should be independent of height. In this study height and the 'frame' variable were both treated as independent variables. 'Frame' alone therefore was a measure of bone width independent of height, but when used in a regression equation together with height the 2 variable provided a measure of both height and bone width simultaneously.

On a common sense basis, one would expect the 'frame' indicator to be poorly correlated with fat content but more highly correlated with FFM. The correlations between the anthropometric measurements FFM and percent fat are shown on Table 61(a). Initially in this analysis the 'Frame' variable was created by standardising the individual bone measurements and summing them as shown below.

i.e. Standardising Ulna = (individual ulna - sample mean ulna)/Sample SD
'Frame' = (Each individual's 4 standardised bone diameters)

In this way the 4 diameters were weighted so that each would have the same degree of influence on the final variable. If this was not carried out then the large measurements would have a disproportionately large influence on 'Frame'.

The program BMDP2R was then used to carry out a stepwise linear regression predicting FFM from the variables below:

1. Arm Circ
2. Thigh Circ
3. Calf Circ
4. Buttocks Circ
5. H
6. W
7. Log (W)
8. Age
9. Age^2
10. 'Frame'

The variables log (W) and Age^2 were used because the relationship between age or W and FFM was not totally linear and in some age ranges it was found to be improved by these transformations,

The program BMDP2R added variables one at a time to the prediction equation, choosing at each step the variable which maximised R and minimised the SE_E.

This stepwise linear regression was carried out with the subjects grouped according to their 'Frame' size and then with all the subjects grouped together, using 'Frame' as a continuous independent variable. The 'Frame' categories were calculated as shown on Table 79. The figures of 2.8 and 0 were chosen because the sample average for 'frame' was approximately 0 with a SD of 2.8 and using these figures ensured a good distribution of the subjects throughout the 4 categories. Table 79 shows that as 'Frame' increased so did mean height, weight, FFM, percent fat and age. An 'ideal' measurement of 'frame' would however be expected to be relatively independent of percent fat and age.

The program BMDP2R showed that in this sample height, calf circumference, log (weight) and age^2 were the 4 most valuable independent variables from the selection available, for predicting FFM in these 'Frame' groups. Table 80 gives the values of R and SE_E using these 4 variables in each group.

The most important statistic on the table is the SE_E, which indicates how much error would be involved when using these regression equations to predict FFM. 95% of the error would lie within $\pm 2SE_E$s.

When 'frame' was used as a continuous variable together with the 4 variables chosen as 'best' within the 'frame' categories, the SE_E was 2.06. Table 80. This value was greater than the SE_E for the small 'frame' group, 1.56kg, but smaller than that for the large 'frame' groups, 2.60kg. Within 'frame' groups, the range of SE_Es was 1.56 to 2.60kgs.

Table 64 in section 3.4.2. gives values for the SE_E when FFM was predicted in age groups using the final 'best' equations. Between the ages of 16 and 39y, the SE_E was always less than or equal to 1.96kg in the Forces sample. It was only in the last 2 age groups which contained only 9% of the Forces male sample, that the SE_E exceeded 2kg and it then ranged between 2.20 and

DEFINITION AND DESCRIPTION OF 'FRAME' CATEGORIES

Table 79

FRAME CATEGORY	DEFINITION	n	Ht(cm)	Wt(kg)	FFM(kg)	% Fat	Age(y)
1	'Frame' $\leq$ -2.8	394	168.1	60.4	51.2	15%	21.2
2	-2.8 < 'Frame' $\leq$ 0	1970	173.5	68.7	56.7	17%	24.1
3	0 < 'Frame' $\leq$ 2.8	1636	178.6	77.3	62.3	19%	27.4
4	2.8 < 'Frame'	311	184.4	89.2	69.7	21%	31.0

'Frame': Sample mean = 0.02 $\pm$ 2.8 units

Prediction of FFM in 'Frame' Categories

Table 80

MALES

'Frame' Groups	Independant Variables	R	SE_E
≤ -2.8 (n = 394)	Height Calf C Log (weight) Age^2	0.92	1.56
-2.8-0 (n== 1970)	Height Calf C Log (weight) Age^2	0.91	1.90
0-2.8 (n = 1636)	Height Calf C Log (weight) Age^2	0.90	2.10
>2.8 (n = 311)	Height Calf C Log (weight) Age^2	0.92	2.60
All (n = 4311)	Height Calf C Log (weight) Age^2 'Frame'	0.95	2.06

2.29kg. This was still less than the SE_E within the top 'frame' category.

Overall, these results suggest that there was no advantage in using these 'frame' categories when compared to using the more simple variable, age, to group the male subjects.

A probable reason for the relatively poor value of 'frame' as an independent variable was that the individual bone diameters are correlated with both fat content and FFM, as shown on Table 61(a). In order to improve this predictive capacity, 'frame' would require to be less dependent on percent fat and therefore a new variable 'bones' was created using only the 2 diameters which had the lowest correlations with percent fat.

'Bones' = (Standardised ulnar D + Standardised biacromial D)

When 'Bones' was used in a prediction equation as the 4th variable together with height, log (weight) and age^2, since these 3 variables conveyed most of the predictive information about FFM, R was calculated as 0.95 and SE_E as 2.03kg. Replacing 'bones' with 'frame' in a similar equation produced a SE_E of 2.09kg.

In addition, the 4 diameters were each used separately as the 4th variable to predict FFM, and ulnar diameter was found to produce the lowest SE_E value.

Table 81

Prediction of FFM using 4 Independent Variables: Males

Subjects	Independent Variables	R	SE_E
All (n=4311)	Height Age^2 Log (weight) Ulnar D	0.95	2.02kg

Subjects	Independent Variables	R	SE_E
All	Height Age^2 Log (weight) 'Bones'	0.95	2.03kg
All	Height Age^2 Log (weight) 'frame'	0.95	2.09kg

It appeared that ulnar diameter was therefore providing a measure of skeletal size relatively independent of height. Why this diameter should be better than the others may be partly explained by the correlations between the diameters, FFM and percent fat as shown on Table 61(a). Although ulnar diameter did not show the highest correlation with FFM, it did show the lowest correlation with percent fat and weight when compared to the other 3 diameters. All the diameters correlated with height to roughly the same extent, with an R value of only about 0.54.

A comparison of the SE_Es in Table 81 shows that of the 3 bony variables shown, ulnar diameter, which was the simplest, produced the lowest SE_E.

The subjects were grouped into 'frame' categories according to their ulnar diameter size. The number of Forces subjects in this section was increased to 5293. Within each age group the mean ulnar diameter was about 5.8 or 5.9cm with a SD of 0.3cm and the cutpoints for the categories were produced from these figures.

Frame 1: Ulna $\leq$ 5.5cm
Frame 2: 5.5 $<$ Ulna $\leq$ 5.8cm
Frame 3: 5.8 $<$ Ulna $\leq$ 6.1cm
Frame 4: Ulna $>$ 6.1cm

Table 82 describes the subjects within these groups. Again, on a common sense basis, one would expect the 'frame' indicator to be more highly related to FFM than percent fat. The small rise in percent fat from 17.2% to 19.1% compared to the large rise in FFM from 54.3kg to 64.5kg supports this idea.

A stepwise linear regression was then carried out within each group using the program BMDP1R, which took the variables height, weight, age and calf circumference and calculated the best regression to predict FFM. These 4 variables were chosen since together with ulnar diameter they had been chosen as the 'best' 5 independent variables for FFM prediction within the earlier 'frame' analysis. The transformations of age and weight as shown on Table 83 improved the accuracy slightly. The results of the regression are shown on Table 83, where R and SE_E within each group are quoted. This range of SE_Es from 1.79 to 2.20kg was similar to the range when FFM was predicted in age groups (section 3.4 Table 63) using ulna as a continuous, independent variable and therefore at first sight the 2 sets of equations appeared to be similar in terms of accuracy.

A problem with any regression equations is that they tend to be population specific i.e. they describe well the population sample from which they were calculated, but when applied to a different sample which may differ in terms of any variable i.e. height or FFM, the equations loose a degree of accuracy. In order to assess this specificity the Forces equations for each ulnar group were then applied to the 1053 civilian males previously described. Table 84.

This table shows that when applied to the civilian sample the values for the SE_Es increased almost by a factor of 3 and the range became 5.29 to 6.07kg. These high values were totally unacceptable and it was therefore concluded that the prediction of FFM in ulnar categories was not feasible.

As will be shown in Section 3.4.8. and on Table 85 however, regressions within age groups using height, weight, calf circumference and ulnar diameter as independent, continuous variables was as accurate in the civilian as the Forces sample.

A possible explanation of this phenomenon may be that ulna appears to be a

Definition and Description of 'Ulnar' Categories

Table 82

Ulnar Group	n	Ht(cm)	Wt(kg)	FFM(kg)	% Fat	Age(y)
≤ 5.5	845	170.8	66	54.3	17.2	23.9
5.51- 5.8	1073	173.5	69.6	57.0	17.7	25.3
5.81- 6.1	2010	176.3	73.7	60.0	18.2	26.6
> 6.1	1365	180.3	80.2	64.5	19.1	29.0

Predicting FFM within Ulnar Diameter Groups, using 4 Independant Variables

Table 83

MALES

Ulnar Groups	Independant Variables	R	SE_E
≤ 5.5 cm (n = 845)	Height Log(wt) Calf C. Age^2	0.94	1.79
5.51 - 5.8 cm (n = 1073)	Height Log(wt) Calf C. Age^2	0.93	1.94
5.81 - 6.1 cm (n = 2010)	Height Log(wt) Calf C. Age^2	0.93	2.01
> 6.1 cm (n = 1365)	Height Log(wt) Calf C. Age^2	0.94	2.20

n = 5293

Ulnar Diameter : Sample Mean = 5.8 ± 0.3 cm

Comparison of the SE_E s when predicting FFM in (a) 'Frame' Groups and (b) Age Groups Table 84

The regression Equations were initially calculated on the Forces Sample, then cross-validated on the Civilians

Category	Subjects	SE_E RANGE		
Frame	Forces	1.79	-	2.20
(ulna D)	Civilians	5.29	-	6.07
Age	Forces	1.54	-	2.29 kg
	Civilians	1.67	-	2.39 kg

valuable indicator of some aspect of FFM which is not so well reflected by the other variables. Putting people into 4 ulnar groups however is similar to giving ulna only 4 possible values and therefore its sensitivity to FFM changes became very much reduced. Within the original Forces sample the accuracy was satisfactory because the regression equations were basically a description of that sample. When applied to the civilian sample, which had slightly different characteristics than the Forces sample, these descriptive equations were no longer accurate.

Within age groups however, ulna was still maintained but as a continuous variable with the complete scope of possible values and therefore it could again reflect FFM changes. Age itself was not such on good predictor variable for FFM and therefore using it as a grouping variable did not cause any loss in accuracy in the cross-validation.

The conclusion from this analysis was that when accurately assessing an individual's FFM by using regression equations, a bony dimension should be included. Within this sample the diameter at the ulna was the 'best' indicator of 'frame' size. It should not however be used to group the individuals since this causes a large decrease in the predictive accuracy, but instead it should be used as a continuous variable within for instance age groups.

It should also be noted however that if only a rough estimate of fatness is required at a group as opposed to an individual level, and tables such as the Life Insurance tables are used, there may be a justification to include categories but these should reflect 'build' and not just skeletal dimensions since muscle mass makes up about 50% of FFM compared to the skeleton's 20%. Quantification of these categories should also be produced otherwise they loose any possible value since their use would depend solely on subjective impressions.

3.4.8. Validation of the Prediction Equations Derived from the Forces Sample, on the Civilian Sample

A commonly acknowledged limitation with any regresssion equation is that it will tend to be population specific i.e. provide an accurate prediction within the population from which it was calculated, but not necessarily with any other population.

In order to test the versatility or specificity of the various regression equations which predicted FFM and were calculated from the Forces sample, they were applied to a civilian sample, and the error between predicted and 'actual' FFM calculated.

(a) Males

A description of both the Forces and civilian male samples used in this analysis are shown in Table 24 and it is immediately obvious that there were differences between the two samples. These differences were described in earlier sections.

Within each age group, the average values for Height did not vary greatly between the two sample populations. The only significant difference was 1.1cm, found in the 20-24y group.

The Forces sample showed higher values for mean weight in each age group when compared with the civilian sample. These differences ranged between 2.3kg and 4.4kg and were significant at the 95% level or above in all age groups over 20y of age.

The mean fat content of the Forces sample was on average 0.7% higher than the civilian sample, and this difference was significant at the 95% level, in the 40-49y groups only. These differences in mean fat content were not large, and it is proposed that because the civilian sample was totally voluntary it is possible that the more 'plump' individuals did not tend to volunteer. The Forces male sample, however, was not so biased, as only approximately 25% were volunteers. It is therefore likely that a more random, representative civilian sample would show higher mean fat contents in each age group.

Mean FFM within the age groups differed between the 2 samples by between 1.6kg and 2.8kg. These differences were significant in all groups over 20yrs at the 99% level, and since they were not due to differences in mean height, this suggested that the Forces sample had larger 'builds' than the civilians. This finding however cannot lead to the general conclusion that the Forces population tends to be more largely 'built' than the civilian population, since the civilian sample in this survey was not considered to be a representative sample.

Table 85 shows the results when the regression equations calculated from the Forces sample were applied to the civilian sample. Values for the SE_E within each age group and using three sets of equations, are shown for both population samples.

It can be seen from Table 85 that the regression using height, calf circumference and log (weight), which was stated to be the most accurate, practical equation on the Forces sample, was not at all accurate on most of the civilian groups. Values for the SE_E ranged from 2.06 to 6.36kg. When the calf measurement was replaced with ulnar diameter, the accuracy improved with many, but not all, age groups and still ranged from 1.74 to 5.58kg.

The inclusion of both the calf and ulnar measurements improved the accuracy in all civilian age groups, reducing the range for the SE_E to between 1.67 and 2.39kg. The mean difference between predicted FFM and FFM calculated using skinfolds was only 0.48 $\pm$ 0.3kg in these civilians. This set of equations also improved the prediction in the Forces sample, reducing the range of SE_E from 1.60-2.50 to 1.54-2.29kg.

These results suggested that the relationship between the independent variables and FFM varied between the Forces and civilian samples in most age groups.

In order to examine the relationship between FFM and the variables height and age a regression equation was calculated between them, with FFM as the dependent variable. An 'F' test similar to the one described in section 3.4.4. was then applied to the civilian and Forces samples both independently and when they were grouped together. When the 2 samples were grouped, the high value for 'F' of 92.5 showed with 99.9% certainty that the relationship between the 3 variables was not the same in the 2 samples. This fact had also been demonstrated in section 3.2. where within height and age groups many significant differences between the two samples were described.

Males: SE_E's within each Forces and Civilian Age Group, when using 3 possible sets of Independent Variables to Predict FFM

Independent Variable	Forces/ Civilian Result	16 SE_E	17–19 SE_E	20–24 SE_E	25–29 SE_E	30–39 SE_E	40–49 SE_E	50–59 SE_E	Total
Height Calf C Log (weight)*	Forces Civilian	1.60 -	1.85 5.50	2.11 5.35	2.13 2.06	1.87 6.36	2.33 6.28	2.50 4.97	
Height Ulnar D Log (weight)*	Forces Civilian	1.55 -	1.75 5.52	2.03 5.58	2.06 1.92	1.76 1.74	2.27 2.09	2.27 5.00	
Height Ulnar D Calf C Weight	Forces Civilian	1.54 -	1.73 1.71	1.95 1.68	1.96 1.92	1.72 1.67	2.20 2.10	2.29 2.39	
N	Forces Civilian	363 -	1084 41	1266 145	790 169	1355 240	406 210	66 201	5294 1006

Note: 1) These values for N are slightly below the total values quoted elsewhere, because the programms BMDPIR and BMDP2R will only calculate results for subjects with no missing variables.

2) The regression equations were initially calculated from the Forces sample and validated with the Civilian sample.

* Some age groups included 'weight' instead of 'log (weight)'.

Male Regression Equations for the Prediction of FFM

Table 86

16yrs

FFM = (15.2 x Height) + (0.542 x Weight) + (0.186 x Calf) + (2.15 x Ulna) - 24.81

17-19yrs

FFM = (17.4 x Height) + (0.466 x Weight) + (0.181 x Calf) + (2.75 x Ulna) - 27.58

20-24yrs

FFM = (20.0 x Height) + (0.410 x Weight) + (0.290 x Calf) + (2.91 x Ulna) - 33.58

25-29yrs

FFM = (22.3 x Height) + (0.387 x Weight) + (0.487 x Calf) + (2.52 x Ulna) - 39.93

30-39yrs

FFM = (17.1 x Height) + (0.487 x Weight) + (0.219 x Calf) + (2.17 x Ulna) - 27.61

40-49yrs

FFM = (20.5 x Height) + (0.354 x Weight) + (0.353 x Calf) + (2.39 x Ulna) - 32.73

50-59yrs

FFM = (26.1 x Height) + (0.278 x Weight) + (0.190 x Calf) + (3.96 x Ulna) - 41.27

Units: Height (m)
Weight, FFM (kg)
Calf, Ulnar (cm)

In the comparison of the Forces and civilian male samples it was concluded that there were differences in 'build' between the 2 populations i.e. differences in FFM independent of height and that they appeared to be reflected at the ulnar, tibial, upper arm and thigh sites. The variables height, weight and calf circumference did not appear to reflect these small 'build' differences between the 2 samples and were therefore able to predict FFM fairly accurately in the original, Forces sample but not in both population samples. Ulnar diameter was therefore chosen by the program BMDP2R as the 'best' indicator of 'build' which was least influenced by other factors such as fat conent.

The validation of the prediction equations on the civilian sample and the inclusion of ulnar diameter to indicate 'build' produced a new set of equations which it is suggested could be applied to different groups of individuals with varying 'builds'. These equations are on Table 86, but further cross-validation on other populations would naturally still be of value.

(b) Females

A description of the Forces and civilian female samples between the ages of 17 and 39y are shown in Table 87.

Table 87

Average Value for Height, Weight, FFM and % Fat in the Forces and Civilian Samples

Forces	n	Height (cm)	Weight (kg)	FFM (kg)	% Fat
17-29	1003	163.7	61.0	43.7	27.9
30-39	51	161.3	60.3	42.0	29.9
Civilians					
17-29	643	163.0	56.8	41.8	26.1
30-39	148	162.2	58.7	41.6	28.7

These differences were described more fully in section 3.2. but it is obvious that small differences exist between the two population samples. The Forces tended to be slightly fatter and have slightly larger FFM values, possibly because of height as opposed to 'build' differences.

Table 88 shows the results when the regression equations chosen as 'best' in the Forces females were applied to the civilians. It shows the values for the SE_E within each age group and sample population.

Table 88

Females: SE_Es within the Forces and Civilian Age Groups, when applying regression Equations

Independent Variables	Forces Civilian Results	17-29y	30-39y
Height Weight Upper Arm C	Forces	1.59	1.44
	Civilians	1.51	1.53

N.B. The regression equations were initially calculated from the Forces sample and validated with the civilian sample.

These results show that when the regressions calculated on the Forces sample were applied to the civilians there was little change in their accuracy. The mean difference between civilian FFM as calculated by skinfolds or these regression equations was 0.2kg in the 17-29y group and -0.11kg in the 30-39y olds. The changes in the SE_E within either age group were too small to be of any great significance.

It was therefore concluded that the equations in section 3.4.6. using height, weight and upper arm circumference to predict FFM were applicable for both the Forces and civilian samples.

The lack of a need for a fourth variable as seen in the male sample, may have been due to the lack of any obvious differences in 'build' between the 2 populations.

These results suggest that the prediction equations calculated from the Forces females are applicable to other female populations who have similar 'builds' relative to their age and height. It is not known how accurate they would be if 'build' differed substantially and therefore a cross-validation with females of varying 'builds' would be useful. For the majority of females however 'build' is unlikely to vary greatly.

3.4.9. 'Smoothing' the Prediction Equations for FFM

(a) Males

Both the methods section and the section on changes in FFM with age, pointed out that using the equations of Durnin and Womersley (1974) which changed with age, produced artifactual 'jumps' in predicted FFM and percent fat between the male decades, starting from the 20-29y age group. In order to smooth these jumps, section 3.2.9. and Graph 9(b) described the calculation in the Forces males of a regression line relating predicted FFM and age, from age 24 to 59y. The age of 24y was chosen as the starting point of the regression because it was just beyond this age that predicted FFM began to decrease.

The average FFM values described previously for each age group did not lie exactly on this regression line, and therefore 'corrections' were calculated for each group average which brought them on to the line and therefore 'smoothed' out the age related changes in FFM. This 'smoothing' process seemed justifiable because there is no known reason why FFM would not alter gradually and smoothly with age. These 'corrections' are shown in Table 89.

Table 89

Male Forces: Corrections Required to 'Smooth' the Pattern of Predicted FFM Between the Age Groups

Age Group (y)	16	17-19	20-24	25-29	30-39	40-49	≥50
Correction	-	-	-	-0.2	+0.3	+0.4	+0.75
Corrected FFM	56.7	57.4	60.3	61.6	60.7	59.4	58.45

Final Male Regression Equations for the Prediction of FFM

Table 90

16yrs

FFM = (15.2 x Height) + (0.542 x Weight) + (0.186 x Calf) + (2.15 x Ulna) - 24.8

17-19yrs

FFM = (17.4 x Height) + (0.466 x Weight) + (0.181 x Calf) + (2.75 x Ulna) - 27.6

20-24 yrs

FFM = (20.0 x Height) + (0.410 x Weight) + (0.290 x Calf) + (2.91 x Ulna) - 33.6

25-29yrs

FFM = (22.3 x Height) + (0.387 x Weight) + (0.487 x Calf) + (2.52 x Ulna) - 40.1

30-39yrs

FFM = (17.1 x Height) + (0.487 x Weight) + (0.219 x Calf) + (2.17 x Ulna) - 27.3

40-49yrs

FFM = (20.5 x Height) + (0.354 x Weight) + (0.353 x Calf) + (2.39 x Ulna) - 32.3

50-56yrs

FFM = (26.1 x Height) + (0.354 x Weight) + (0.190 x Calf) + (3.96 x Ulna) - 40.5

Units: Height (m)
Weight, FFM (kg)
Calf, Ulnar (cm)

Table 89 also includes the 'corrected' average values for FFM within each age group.

Since any regression equation calculated from the Forces sample to predict FFM in age groups will inherently also reflect the 'jumps' previously described, these equations also require to be 'smoothed'. The corrections shown on Table 89 were therefore applied to the equations described in section 3.4.4. and the final 'recommended' prediction equations are listed on Table 90.

(b) Females

A similar 'smoothing' was not required for the female equations because although the equations of Durnin & Womersley (1974) produced an increase of 2% in mean fat content from the 20 to the 30y olds at the same sum of skinfolds, and this therefore caused a slight 'jump' in the predicted FFM between the 17-29y olds and 30-39y olds, the magnitude of the 'jump' was small enough to be of little consequence.

The final prediction equations for the female sample were still as described in section 3.4.6. and below:

Table 91

17-29y

FFM = (10.9 x Height) - (0.51 x Upperarm C) + (0.563 x Weight) + 5.6

30-39y

FFM = (14.7 x Height) + (0.14 x Upperarm C) + (0.397 x Weight) - 9.6

Units: Height (m)
Upperarm (cm)
Weight (kg)
FFM (kg)

3.4.10. Possible Errors in the Prediction of FFM Due to Experimental Error in Variable Measurement

When using regression equations to predict a variable such as FFM in field studies, it is particularly useful to know how accurately the individual measurements must be taken, and what effect small variations in the measurements have on the dependent variable. To this end, the prediction equation calculated for 30-39y old males, which used the four independent variables height, weight, calf circumference and ulnar diameter to predict FFM, was manipulated by using a couple of slightly different values for each independent variables, and noting the effect on predicted FFM. These results are shown in Table 92.

Equation for 30-39y old males

FFM (kg) = (17.1 x Height(m)) + (0.478 x Weight (kg)) +

(0.219 x Calf (cm)) + (2.17 x Ulna (cm)) - 27.3

Table 92

Variable Altered	Variable Alteration	Change in predicted FFM caused by Change in Independent Variable
Height (m)	1.70 - 1.75	0.85kg
	1.80 - 1.82	0.34kg
Weight (kg)	65 - 67	0.96kg
	70 - 71	0.48kg
Calf C (cm)	40 - 42	0.44kg
	37 - 38	0.22kg
Ulna (cm)	5.4 - 5.8	0.88kg
	5.8 - 6.0	0.44kg

The results from other age groups would be similar.

Small variations of about 2cm in measured height could occur if a subject did not adapt the correct stance on the stadiometer. An error of 2cm however would only alter the FFM estimation by 0.34kg in this 30-39y group and therefore is not very important.

Variations of about 1kg in measured weight could be caused by changes in fluid balance or inaccurate scales, but since the difference in predicted FFM would only be by 0.45kg these small weight variations are also not very important. Larger errors in the measurement of weight which would most likely be caused by inaccurate scales, could alter the accuracy of the prediction substantially. It is therefore important that when using these regression equations, weight should only be taken from scales, accurate to at least ± 1kg.

An error in a calf measurement of 1cm, caused an error in the predicted FFM of 0.22kg. The reproducibility study in Chapter 2 however, demonstrated that the mean modulus of the difference between the measurements of 2 observers at this site was only 0.24 ± 0.2cm. It is therefore unlikely that an experienced field worker would produce an error of more than 1cm at this site. An inexperienced field worker producing an error of 2cm would still only alter the prediction by 0.44kg.

The reproducibility study showed that experienced field workers using a bone vernier never produced a difference in measured ulnar diameter of more than 0.2cm. This error would alter the prediction by 0.44kg in the 30-39y male group. When new field workers were being taught the measurements, it was noted that the ulnar diameter was one of the easiest to learn and measure accurately. It is therefore believed that errors of over 0.2cm would be unlikely even with inexperienced field workers using a bone vernier. If an accurate vernier was not used for this measurement however, larger errors could be expected. An error of about 0.5cm in the measurement altered predicted FFM by 1.1kg in the 30-39y group.

In conclusion, it was believed that small measurement errors would not greatly alter the accuracy of any prediction of FFM, as there was no obvious reason for these resulting errors to be all in the same direction. It is likely that many would cancel out.

3.4.11. <u>Comparison of the Errors Involved when assessing 'Fatness' using W/H^2, Tables of Recommended Weight for Height and the Prediction Equations Calculated in this Study: Males</u>

Of the possible field methods previously mentioned for assessing fat content the most popular are probably the tables of recommended 'Weight for Height' and the Quetelet Index, W/H^2.

(a) Quetelet Index Ranges

This index can be of value in population studies where the aim is to assess groups of people. Various ranges of 'desirable' W/H^2 values have been suggested. Garrow (1981) after examining mortality figures, suggested 4 groups, from the 'non-obese' to the 'exceedingly obese'

Grade 0: W/H^2 20-24.9
Grade 1: W/H^2 25-29.9
Grade 2: W/H^2 30-40.0
Grade 3: W/H^2 40

A British report published by the DHSS/MRC Group in 1976 however, suggested alternative ranges and based their results on the 'desirable' weights for height given by the Metropolitan Life Insurance Company Tables.

		'Desirable' Range			'Desirable' Range
Men	Small Frame :	19.7-21.2	Women	Small Frame :	19.1-20.6
	Medium Frame:	20.7-22.9		Medium Frame:	20.1-22.5
	Large Frame :	22.1-24.9		Large Frame :	21.4-24.6

In some aspects, the 2 sets of ranges are in agreement since all the 'desirable' ranges in the latter study fit into the 'non-obese' range of 20-24.9 in the former study. On the other hand, Garrow produced very wide ranges since he was attempting to assess 'obesity' while the DHSS/MRC group were trying to assess the slightly finer aspect of 'desirable' W/H^2, based on an underlying assumption that this would reflect some 'desirable' fat content. Within Garrow's range of 20-24.9 he accepted that not every individual would have an exactly 'desirable' fat content, but he estimated that most would be close to their 'desirable' levels. The data in this study however have shown that in males a range of fat contents from 7 to 30% fat was related to W/H^2 values of less than 25. See Graph 1(a). In females this range was from about 18 to 38% fat. There is obviously no accuracy in using these W/H^2 ranges. If 20% fat was taken as about the maximum 'desirable' male fat content and 30% the female equivalent then within this Forces sample about 16% of both sexes within the W/H^2 range 20-24.9 had fat contents which were too high.

The possible errors incurred when using an individual's W/H^2 value to assess his 'desirable' weight as suggested by the DHSS/MRC group, were discussed in more detail in the Methods chapter. It was concluded there that in order to get the most accurate results using W/H^2, age had to be taken into account when using the index and age related equations have been calculated by other workers such as Norgan and Ferro-Luzzi (1982). This group found an increase in the accuracy of prediction when age plus W/H^2 were used to predict percent fat as opposed to W/H^2 alone.

In order to compare the accuracy of the prediction equations already calculated from the Forces sample with the maximum possible accuracy of W/H^2, regression equations were calculated for each age group which predicted percent fat using W/H^2 as the independent variable. Table 93 describes these equations for both the male and female Forces samples and Table 94 describes the SE_Es from both sets of age related equations. On this 2nd table, the SE_Es from the percent fat predictions were converted into kgs, assuming weights of 75kg and 60kg for the males and females respectively.

Table 94 demonstrates that even within age groups the male W/H^2 equations were not quite as accurate as the original equations which had predicted FFM using height, weight, calf circumference and ulnar diameter. In the civilians, the mean difference between FFM calculated using skinfolds and the regression equations initially calculated on the Forces sample was 0.48 $\pm$ 0.3kg using the 4 independent variables and 0.54 $\pm$ 0.20kg using the W/H^2 equations. The range of SE_Es went from 1.54-2.39kg to 1.78-3.52kg using the W/H^2 equations. Although differences in the SE_Es were small within most age groups except the 50y olds as each subject's weight increased the magnitude of the SE_E in kg also increased when using the W/H^2 equations. A SE_E of 3% fat for instance, would represent 2.1kg in a 75kg man but 2.7kg in a 90kg man, and $\pm$ 2 SE_Es, within which 95% of the prediction errors would occur, would increase from $\pm$ 4.2kgs to $\pm$ 5.4kgs. This is a substantial decrease in accuracy.

Since heavy individuals are more likely to be 'overfat' than light

Linear Regression Equations of % Fat on W/H^2 Within Age Groups — Table 93

MALES

Age Group (yrs)	Intercept term	Regression Coefficient	R	SE_E	n
16	-9.5	1.07	0.66	2.37	363
17-19	-13.9	1.33	0.76	2.62	1048
20-24	-13.9	1.30	0.78	2.87	1266
25-29	-11.1	1.18	0.77	2.92	790
30-39	-2.86	0.96	0.76	2.45	1354
40-49	-5.12	1.17	0.73	3.08	406
≥50	-6.68	1.31	0.82	3.08	66

FEMALES

Age Group (yrs)	Intercept term	Regression Coefficient	R	SE_E	n
17-19	1.10	1.18	0.76	2.59	403
20-24	-1.62	1.30	0.77	2.89	483
25-29	-1.39	1.26	0.73	3.58	117
30-39	3.89	1.13	0.77	2.37	51

Table 94

Comparison of the SE_Es when using Different Independent Variables to Predict FFM or % Fat: Males and Females

Cross-Validation of Regression Equations Calculated from the Forces samples, with Civilian Samples

MALES

Independent Variables	Dependent Variables	Forces/Civ	16	17-19	20-24	25-29	30-39	40-49	≥50
Height Ulnar D Calf C Weight	FFM FFM	Forces Civilian	1.54 -	1.73 1.71	1.95 1.68	1.96 1.92	1.72 1.67	2.20 2.10	2.29 2.39
Age W/H^2	% Fat % Fat	Forces Civilians	2.37 -	2.62 2.44	2.87 2.61	2.92 2.85	2.45 2.49	3.08 3.00	3.08 4.69
	FFM* FFM*	Forces Civilians	1.78 -	1.96 1.83	2.15 1.96	2.19 2.13	1.84 1.87	2.31 2.25	2.31 3.52

FEMALES

Height Upperarm C Weight	FFM FFM	Forces Civilians	- -	1.44 1.51	1.65	1.80	1.44 1.53
Age W/H^2	% Fat % Fat	Forces Civilians	- -	2.59 2.33	2.89 2.68	3.58 2.81	2.37 2.52
	FFM* FFM*	Forces Civilians	- -	1.55 1.40	1.73 1.61	2.15 1.69	1.42 1.51

* Transformation of the SE_E from % Fat to kgs was made assuming a male weight of 75kg and a female weight of 60kg.

individuals a decrease in accuracy with increasing weight is not very acceptable if one is attempting to pinpoint these 'over-fat' individuals and assess their 'desirable' weights.

Within the female sample, it was again the case that the W/H^2 equations were not quite as accurate as the original equations which had used height, weight and upper arm circumference to predict FFM. The mean difference between FFM calculated from skinfolds and from using the 2 sets of anthropometric equations on the civilian sample was 0.17kg using the 3 independent variables and 0.45kg using the W/H^2 age equations. The SE_E range was 1.44 to 1.80kg with the original equations but increased to 1.40 to 2.15kg using the W/H^2 equations.

It is also suggested that the equations predicting FFM may tend to be less population specific than the equations predicting percent fat. The logic behind this idea is that regression equations basically describe the population sample from which they were derived and if they are used on a dissimilar sample they still tend to attribute to that sample the characteristics of the original population sample. In this way, if percent fat was being predicted and the original sample had a mean fat content of 20% of body weight and a SD of 10% fat, the regression equation derived from this sample would tend to predict fat contents around 20% $\pm$ 10% on any other samples even if those samples had fairly different means and SDs. This would also be the case if FFM was being predicted.

Because of the differences in 'build' between the civilian and Forces sample however, the final FFM prediction equations were modified, allowing them to take into account these 'build' differences. It was believed that as a result, small differences in 'build' and thus FFM between the original population sample and other samples would also be taken into account by the final equations and therefore that they were fairly adaptable.

On the other hand, because there were few differences in the fat contents of the civilian and Forces samples within each age group, this meant that the equations predicting percent fat had never been cross-validated on a sample which was very different from the original sample. Their accuracy on a sample with a different fat distribution was therefore unknown.

For these reasons it was concluded that the W/H^2 equations were not as accurate or useful as the regression equations described in Chapter 3.4.9.

(b) Army Tables of 'Desirable Weight for Height'

The standard Army tables which are used as a guide to an individual's 'desirable' weight were derived from data collected by the Metropolitan Life Insurance Company of New York (1959), and were described in Chapter 2, Table 6.

Within each 2cm height range in the male Army tables, there is a permitted weight range which includes 3 'frame' categories, of from 22 to 29.5kg. Within a 'frame' category the range from 'desired' to permitted weight is anything between 10kg and 17kg.

In this Forces sample, the SD of FFM within a 2cm height group averaged about 5kg therefore 95% of the individuals in the 2cm group would fall within a FFM range of 20kg. As a result these wide ranges of permitted weights on the tables were required in order to encompass the FFM variations between individuals, but if 'frame' was incorrectly assessed errors of over 20kg could be produced when calculating 'desirable' or 'permitted' weight. If 'frame' was correctly assessed, these errors could still be over about 10kg. It is not possible to put an exact figure on these possible errors because of the subjective impression required to tell if 'frame' is correctly or incorrectly assessed.

It is therefore obvious from the wide range of FFM values within any 2cm height group, that no single 'desirable' weight can be correct for all individuals and although the large 'permitted' range in the 'height/weight' table would allow for most people's likely 'desirable' weight, it would also allow some individuals to be 20kg or more 'overweight'. The maximum 'permitted' weight was 17kg over the 'desirable' weight and this allowed an 87kg, large framed man 188cm tall with 15% of his weight as fat, to reach about 30% fat before being over the 'permitted' weight. This is too far from a 'desirable' fat content to be 'permitted'.

(c) Male Prediction Equations

100 male subjects aged between 16 and 55y were randomly selected from the

Forces sample. The FFM of each individual was predicted using the variables height, weight, calf circumference and ulnar diameter and the age related prediction equations calculated in section 3.4.9. Graph 13 shows the errors i.e. (True - Predicted) FFM, 'True' FFM having been predicted using the equations of Durnin and Womersley (1974).

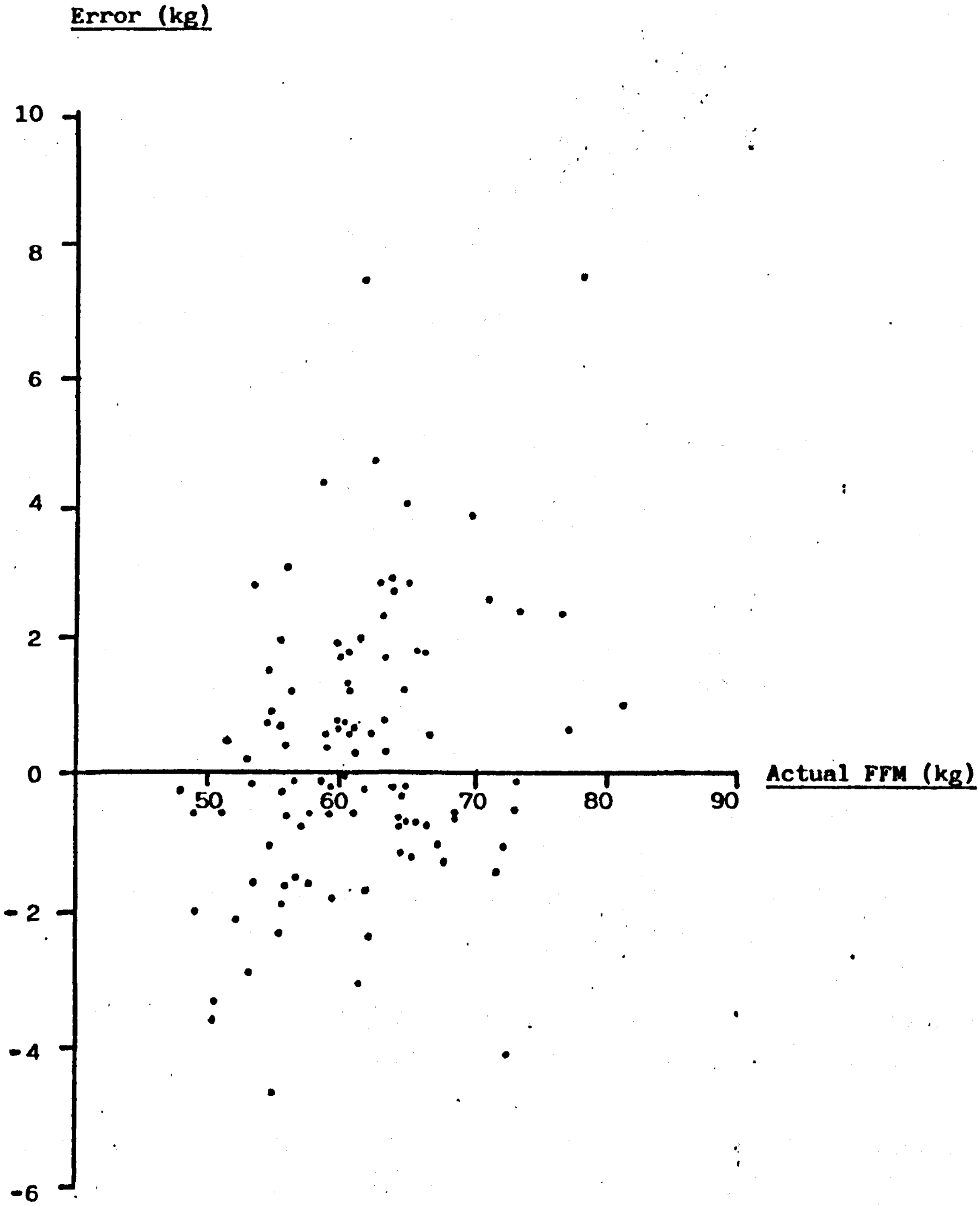
The graph shows that in this sample only 2% had errors more than $\pm$ 6kg, 92% had errors of less than $\pm$ 4kg and about 70% had errors of less than or equal to $\pm$ 2kg. This result was as expected, since the SE_Es of the 7 age equations ranged from 1.54 to 2.29kg in the Forces sample i.e. 67% of the errors would fall within $\pm$ 1SE_E and 95% between $\pm$ 2SE_Es.

In this random sample of 100 men, the maximum error when using the prediction equations was 7.7kg and was found in a tall 'well-built' 21y old. Within the total male sample there were no errors over 10kg. The maximum error was therefore still less than the maximum possible error within one 'frame' category of the Army tables, and was well below the maximum possible error for a complete 2cm height group. The accuracy was also better than when W/H^2 equations were used to assess 'desirable' weight.

Using the prediction equations therefore eliminated the problem of subjectively assessing 'frame' size and also reduced the range of likely errors when assessing 'desirable' weight to within $\pm$ 6kg for about 98% of both the Forces and civilian samples. This represents a large increase in the accuracy of prediction.

FFM versus (Actual -Predicted FFM) (kg)

Males n = 100



REFERENCES

ADAM, J.M., ALLAN, J.R., LEWIS, H.E., DAR, S.N. and ROSENBAUM, S. (1962). Lean and far body mass and their relationship to physical efficiency. Army Personnel Research Committee Report 62/9.

ALEXANDER, M.L. (1964). The postmortem examination of total body fat, muscle and bone. Clin. Sci. 26, 193-202.

ALLEN, T.H., PENG, M.T., CHEN, K.P., HUANG, T.F., CHANG, C. and FANG, H.S. (1956). Prediction of total adiposity from skinfolds and the curvilinear relationship between external and internal adiposity. Metabolism 5, 346-352.

ANDERSON, E.C. and LANGHAM, W.H. (1959). Average potassium concentration of the human body as a function of age. Science 130, 713-714.

BAIRD, I.M., SILVERSTONE, J.T., GRIMSHAW, J.J. and ASHWELL, M. (1974). Prevalence of obesity in a London borough. Practioner 212, 706-714.

BAKER, P.T. and ANGEL, J.L. (1965). Old age changes in bone density: sex and race factors in the United States. Human Biol. 37, 104-121.

BAKKER, H.K. and STRUIKENKAMP, R.S. (1977). Biological variability and lean body mass estimates. Human Biol. 49, 187-202.

BEHNKE, A.R., FEEN, B.G. and WELHAM, W.C. (1942). Specific gravity of healthy men: Body weight - body volume as an index of obesity. J. Amer. Med. Assoc. 118, 495-498.

BEHNKE, A.R., OSSERMAN, E.F. and WELHAM, W.C. (1953). Lean body mass. Arch. Intern. Med. 91, 585-601.

BEHNKE, A.R. (1959). The estimation of lean body weight from 'skeletal' measurements. Human Biol. 31, 295-315.

BEHNKE, A.R., GUTTENTAG, O.E. and BRODSKY, C. (1959). Quantification of body weight and configuration from anthropometric measurements. Human Biol. 31, 213-234.

BEHNKE, A.R. (1961a). Anthropometric fractionation of body weight. J. Appl. Physiol. 16, 949-954.

BEHNKE, A.R. (1961b). Quantitative assessment of body build. J. Appl. Physiol. 16, 960-968.

BEHNKE, A.R. (1963). Anthropometric evaluation of body composition throughout life. Ann. N.Y. Acad. Sci. 110, 450-464.

BILLEWICZ, W.Z., KEMSLEY, W.F.F. and THOMSON, A.M. (1962). Indices of adiposity. Brit. J. prev. sec. Med. 16, 183-188.

BISCHOFF (1863). Z. ration. Med. 20, 75. Quoted by Widdowson (1965).

BOOTH, R.A.D., GODDARD, B.A., PATON, A. (1966). Measurement of fat thickness in man: a comparison of ultrasound, Harpenden calipers and electrical conductivity. Br. J. Nutr. 20, 719-725.

BROCKET, J.E., BROPHY, M., KONISHI, F., MARCINEK, J.G., GROTHEER, M.P., MICHALOWICZ, W.A., KASHIN,P. and GROSSMAN, M.I. (1956). Influence of body size, body fat, nutrient intake and physical fitness on the energy expenditure of walking. US ARMY MED. NUTR. LAB. REPT. No 177.

BROWN, W.J. and JONES, P.R.M. (1977). The distribution of body fat in relation to physical activity. Ann. hum. Biol. 4, 537-550.

BROZEK, J. (1952). Changes in body composition in man during maturity and their nutritional implications. Fed. Proc. 11, 784-793.

BROZEK, J. (1955). Role of anthropometry in the study of body composition: towards a synthesis of methods. Ann. N.Y. Acad. Sci. 63, 491-504.

BROZEK, J., GRANDE, F., AMDERSON, J.T. and KEYS, A. (1963). Densitometric analysis of body composition: revision of some basic assumptions. Ann. N.Y. Acad. Sci. 110, 113-140.

BROZEK, J. and KEYS, A. (1951). The evaluation of leaness - fatness in man. Br. J. Nutr. 5, 194-206.

BROZEK, J. and KINSEY, W. (1960). Age changes in skinfold compressability. J. Geront. 15, 45-51.

BROZEK, J. and MORI, H. (1958). Some interrelations between somatic, roentgenographic and densitometric criteria of fatness. Human Biol. 30, 322-336.

BURKINSHAW, L., JONES, P.R.M. and KRUPOWICZ, D.W. (1973). Observer error in skinfold thickness measurements. Human Biol. 45, 273-279.

BURMEISTER, W. and BINGERT, A. (1967). Quantitative changes in the human cell mass between the 8th and 90th year of life. Klin. Wschr. 45, 409-416.

CARLSON, L.A. and BOTTINGER, L.L. (1972). Ischaemic heart disease in relation to fasting values of plasma triglycerides and cholesterol. Lancet 1, 865-868.

CHINN, K.S.K. and ALLEN, T.H. (1960). Body fat in men from 2 skinfolds, height, weight and age. US Army Med. Res. Nutr. Lab. Rept. No 248

CROWDY, J.P. (1978). Obesity and the soldier. Army Medical Directorate Bulletin (Third Series) no 2. London: HMSO

DAMON, A. and GOLDMAN, R.F. (1964). Predicting fat from body measurements: densitometric validation of 10 anthropometric equations. Human Biol. 36, 32-44.

DEPARTMENT OF HEALTH AND SOCIAL SECURITY/MEDICAL RESEARCH COUNCIL (1976). Research on Obesity. Compiled by W.P.T. James. London: HMSO

von DOBELN, W. (1959). Anthropometric determination of fat free body weight. Acta. Med. Scand. 165, 37-40.

DUBOIS, E.F. (1936). Basal Metabolism in Health and Disease. 3rd edn. ed Philadelphia: Lea & Febinger.

DUPERTIUS, C.W., PITTS, G.C., OSSERMAN, E.F., WELHAM, W.C. and BEHNKE, A.R. (1951). Relation of specific gravity to body build in a group of healthy men. J. Appl. Physiol. 3, 676-680.

DURNIN, J.V.G.A. and RAHAMAN, M.M. (1967). The assessment of the amount of fat in the human body from measurement of skinfold thickness. Br. J. Nutr. 21, 681-688.

DURNIN, J.V.G.A. and WOMERSLEY, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16 to 72 years. Br. J. Nutr. 32, 77-97.

DYER, A.R., STAMLER, J., BERKSON, D.M. and LINDBERG, H.A. (1975). Relationship of relative body weight and body mass index to 14y mortality in the Chicago People's Gas Company study. J. Chronic Dis. 28, 109-123.

EDWARDS, D.A.W. (1950). Observations on the distribution of subcutaneous fat. Clin. Sci. 9 259-270.

EDWARDS D.A.W. (1951). Differences in the distribution of subcutaneous fat with sex and maturity. Clin. Sci. 10, 305-315.

EDWARDS, K.D.G. and WHYTE, H.M. (1962). The simple measurement of obesity. Clin. Sci. 22, 347-352.

FLETCHER, R.F. (1962). The measurement of total body fat with skinfold calipers. Clin. Sci. 22, 333-346.

FLINT, M.M., DRINKWATER, B.L., WELLS, C.L. and HORVATH, S.M. (1977). Validity of estimating body fat of females: effect of age and fitness. Human Biol. 49, 559-572.

FORBES, G.B. (1976). The adult decline in lean body mass. Human Biol. 48, 161-173.

FORBES, G.B. and AMIRHAKIMI, G.H. (1970). Skinfold thickness and body fat in children. Human Biol. 42, 401-418.

FORBES, R.M., COOPER, A.R. and MITCHELL, H.H. (1953). The composition of the adult human body as determined by chemical analysis. J. Biol. Chem. 203, 359-366.

FORBES, R.M., MITCHELL, H.H. and COOPER, R.A. (1956). Further studies on the gross composition and mineral elements of the adult human body. J. Biol. Chem. 223, 969-975.

FORBES, G.B. and REINA, J.C. (1970). Adult lean body mass decline with age: some longitudinal observations. Metabolism 19, 653-663.

FRISANCHO, A.R. and FLEGEL, P.N. (1983). Elbow breadth as a measure of frame size for US males and females. Am. J. Clin. Nutr. 37, 311-314.

GARN, S.M. (1954). Fat patterning and fat intercorrelations in the adult male. Human Biol. 26, 59-69.

GARN, S.M. (1957). Roentgenogrammetric determinations of body composition. Human Biol. 29, 337-353.

GARN, S.M. (1956). Comparison of pinch-caliper and x-ray measurements of skin plus subcutaneous fat. Science 24, 178-179.

GARN, S.M. and GORMAN, E.L. (1956). Composition of pinch-caliper and teleroentgenogrammetric measurements of subcutaneous fat. Human Biol. 28, 407-413.

GARN, S.M., PESICK, S.D. and HAWTHORNE, V.M. (1983). The bony chest breadth as a frame size standard in nutritional assessment. Am. J. Clin. Nutr. 37, 315-318.

GARN, S.M., ROHMANN, C.G. and WAGNER, B. (1967). Bone loss as a general phenomena in man. Fed. Proc. 26, 1729-1736.

GARROW, J.S. (1981). Treat Obesity Seriously. A clinical manual. Edinburgh: Churchill Livingston.

GOLDBOURT, U. and MEDALIE, J.M. (1974). Weight-height indices. Choice of the most suitable index and its association with selected variables among 10,000 adult males of heterogeneous origin. Brit. J. Prev. Soc. Med. 28, 116-126.

GOLDSTEIN, H. (1974). Some statistical considerations on the use of anthropometry to assess nutritional status. In Advances in Experimental Medicine and Biology: Nutrition and Malnutrition. Identification and Measurement vol 49, ed. Roche and Falkner. London: Plenum Press.

GORDON, T. and KANNEL, W.B. (1973). The effects of overweight on cardiovascular disease. Geriatrics 28(8), 80-88.

GRANDE, F. (1970). Correspondence. Metabolism 11, 1006-1007.

GRANDE, F. (1973). Obesity in Perspective. Vol. 2, Part 2. ed. Bray, G.A.

HAISMAN, M.F. (1970). The assessment of body fat content in young men from measurements of body density and skinfold thickness. Human Biol. 42, 679-688.

HAMMOND, W.H. (1955). Measurement and interpretation of subcutaneous fat, with norms for children and young adult males. Br. J. prev. soc Med. 9, 201-211.

HARRINGTON, G. (1963). The separation of technical errors and biological variation, and other statistical problems arising in body composition studies. Ann. N.Y. Acad. Sci. 110, 642-653.

HARRISON, G.G. and Van ITALLIE, T.B. (1982). Estimation of body composition: a new approach based on electromagnetic principles. Am. J. of Clin. Nutr. 35, 1176-1179.

HECHTER, H. (1959). The relationship between weight and some anthropometric measurements in adult males. Human Biol. 31, 235-243.

HUNT, E.E. (1958). Human growth and body form in recent generations. Am. Anthrop. 60, 118-131.

Van ITALLIE, T.B. (1979). Obesity: Adverse effects on health and longevity. Am. J. Clin. Nutr. 32, 2723-2733.

JONES, P.R.M., BHARADWAJ, H., BHATIA, M.R. and MALHOTRA, M.S. (1977). Differences between ethnic groups in the relationship of skinfold thickness to body density. In Selected Topics in Environmental Biology. ed. Bhatia. B., Chhina, G.S. and Singh, B. Oxford: Pergamon Press.

KATCH, F.I., BEHNKE, A.R. and KATCH, V.L. (1979). Estimation of body fat from skinfolds and surface area. Human Biol. 51, 411-424.

KATCH, V.L. and FREEDSON, P.S. (1982). Body size and shape: derivation of the 'HAT' frame size model. Am. J. Clin. Nutr. 36, 669-675.

KATCH. F.I. and McARDLE, W.D. (1973). Prediction of body density from simple anthropometric measurements in college-age men and women. Human Biol. 45, 445-454.

KATCH, K.I. ans MICHAEL, E.D. (1969). Densitometric validation of six skinfold formulas to predict body density and percent body fat of 17y old boys. Res. Quart. 40, 712-716.

KEMSLEY, W.F.F. (1950). Weight and height of a population in 1943. Ann. Eugen. 15, 161-183.

KEYS, A. (1980). W.O. Atwater memorial lecture: Overweight, obesity, coronary heart disease and mortality. Nutrition Reviews 38, 287-307.

KEYS, A. and BROZEK, J. (1953). Body fat in adult man. Physiol. Rev. 33, 245-325.

KEYS, A., FIDANZA, F., KARVONEN, M.J., KIMURA, N. and TAYLOR, H.L. (1972). Indices of relative weight and obesity. J. Chron. Dis. 25, 329-343.

KRZYWICKI, H.J. and CHINN, K.S.K. (1967). Body composition of a military population, Fort Carson, 1963. Am. J. Clin. Nutr. 20, 708-715.

LANGE, K.O. and BROZEK, J. (1961). A new model of skinfold caliper. Am. J. Phys. Anthrop. 19, 98-99.

LASKER, G.W. (1953). The age factor in bodily measurements of adult male and female Mexicans. Human Biol. 25, 50.

LEE, J., KOLONEL, L.N. and HINDS, M.W. (1981). Relative merits of the weight-corrected-for height indices. Am. J. Clin. Nutr. 34, 2521-2529.

Von LIEBIG, G. (1874). Gewichtsbestimmunggen der Organe des menschlichen. Korpers. Arch. f. Anat., Physiol. und wiss. Med. Pg 96.

LINDAHL, D. and LINDGREN, A.G.M. (1962). Grading of osteoporosis in autopsy specimens. Acta. Orthop. Scand. 32, 87-100.

LOHMAN, T.G. (1981). Skinfolds and body density and their relation to body fatness: A review. Human Biol. 53, 181-225.

MAINLAND, D. (1957). A study of age differences in x-ray density of 5 bones in adult wrist and hand. J. Geront. 12, 284-291.

MALINA, R.M. (1966). Patterns of development in skinfolds of Negro and White Philadelphia children. Human Biol. 38, 89-103.

MATIEGKA, J. (1921). The testing of physical efficiency. Am. J. Phys. Anthropol. 4, 223-230.

McCANCE, R.A. and WIDDOWSON, E.M. (1951). A method of breaking down the body weight of living persons. Proc. Roy. Soc. London. Series B. 138, 115-130.

METROPOLITAN LIFE INSURANCE COMPANY (1943). Ideal weights for men. Statist. Bull. June 1943

METROPOLITAN LIFE INSURANCE COMPANY (1942). Ideal weights for women. Statist. Bull. October 1942

METROPOLITAN LIFE INSURANCE COMPANY (1960). Mortality among overweight men. Statist. Bull. 41 (February)

METROPOLITAN LIFE INSURANCE COMPANY (1960) Mortality among overweight women. Statist. Bull. 41 (March)

METROPOLITAN LIFE INSURANCE COMPANY (1959). New weight standards for men and women. Statist. Bull. 40 (November-December)

MIALL, W., ASHCROFT, M., LOVELL, H. and MOORE, F. (1967). A longitudinal study of the decline of adult height with age in two Welsh communities. Human Biol. 39, 445-454.

MICHAEL, E.D. and KATCH, F.I. (1968). Prediction of body density from skinfold and girth measurements of 17-year-old boys. J. Appl. Physiol. 25, 747-750.

MILLER, C.E. and REMENCHIK, A.P. (1963). Problems involved in accurately measuring the potassium content of the human body. Ann. N.Y. Acad. Sci. 110, 175-188.

MILNE, J.S. and LAUDER, I.J. (1974). Age effects in kyphosis and lordosis in adults. Ann. hum. Biol. 1, 327.

MITCHELL, H.H., HAMILTON, T.S., STEGGERDA, F.R. and BEAN, H.W. (1945). Chemical composition of the adult human body and its bearing on the biochemistry of growth. J. Biol. Chem. 158, 625-637.

MINISTRY OF DEFENCE. Abstract of Army manpower statistics no. 88. 1978-79 London: HMSO

MONTEGRIFFO, V.M.E. (1968). Height and weight of a United Kingdom adult population with a review of anthropometric literature. Ann. Hum. Genet. Lond. 31, 389-399.

MOORE, F.D., OLSEN, K.O., McMURRAY, J.D., PARKER, H.V., BALL, M.R. and BOYDEN, C.M. (1963). The Body Cell Mass and its Supporting Environment. Philadelphia, Pa: Saunders.

MUELLER, W.H. and STALLONES, L. (1981). Anatomical distribution of subcutaneous fat: skinfold site choice and construction of indices. Human Biol. 53, 321-335.

MYHRE, L.B. and KESSLER, W. (1966). Body density and potassium 40 measurements of body composition as related to age. J. Appl. Physiol. 21, 1251-1255.

NATIONAL CENTRE FOR HEALTH STATISTICS (1974). Skinfold thickness of youths 12-17y. Unites States, DHEW. Pub no (HRA) 74-614, Series 11, 132 Rockville, Maryland.

NOPPA, H., ANDERSON, M., BENGTSSON, C., BRUCE, A. and ISAKSSON, B. (1979). Body composition im middle-aged women with special reference to the correlation between body fat mass and anthropometric data. Am. J. Clin. Nutr. 32, 1388-1395.

NOPPA, H., BENGTSSON, C., WEDEL, H. and WILHELMSEN, L. (1980). Obesity in relation to morbidity and mortality from cardiovascular disease. Am. J. Epid. 3, 682-692.

NORGAN, N.G. and FERRO-LUZZI, A. (1982). Weight-height indices as estimators of fatness in men. Human Nutrition: Clinical Nutrition. 36c, 363-372.

OFFICE OF POPULATION CENSUSES AND SURVEYS 1979 population estimates, England and Wales. London: HMSO

OFFICE OF POPULATION CENSUSES AND SURVEYS (1981). Adult heights and weights survey. Ref. SS81/1. London: HMSO

PACE, N., KLINE, L., SCHACHMAN, H.D. and HARFENIST, M. (1947). Studies on body composition: IV Use of radioactive hydrogen for measurement in vivo of total body water. J. biol. Chem. 168, 459-469.

PARNELL, R.W. (1958). Behaviour and Physique: an Introduction to Practical and Applied Somatometry. London: E. Arnold.

PASCALE, L.R., GROSSMAN, M.I., SLOANE, H.S. and FRANKEL, T. (1956). Correlations between thickness of skinfolds and body density in 88 soldiers. Human Biol. 28, 165-176.

PAUL, O., LEPPER, M.H., PHELAN, W.H., DUPERTIUS, G.W., MACMILLAN, A., MCKEAN, H. and PARK, H. (1963). Longitudinal study of coronary heart disease. Circulation 28, 20-31.

PIERSON, W.R. (1963). A photogrammetric technique for the estimation of surface area and volume. Ann. N.Y. Acad. Sci. 110, 109-112.

POLLOCK, M.L., HICKMAN, T., KENDRICK, Z., JACKSON, A., LINNERUD, A.C. and DAWSON, G. (1976). Prediction of body density in young and middle- aged men. J. Appl. Physiol. 40, 300-304.

POLLOCK, M.L., LAUGHRIDGE, E.E., COLEMAN, B., LINNERUD, A.C. and JACKSON, A. (1975). Prediction of body density in young and middle aged women. J. Appl. Physiol. 38, 745-749.

THE POOLING PROJECT RESEARCH GROUP (1978). Relationship of blood pressure, serum cholesterol, smoking habit, relative weight and ECG abnormalities to incidence of major coronary events: Final report of the Pooling Project J. Chronic. Dis. 31, 201-306.

PYORALA, K. (1978). CVD Epidem. Newsletter 25, 33-34.

REYNOLDS, E.L. (1951). The distribution of subcutaneous fat in childhood and adolescence. Monograms of the Society for Research in Child Development. 15(2). Serial No. 50.

REYNOLDS, E.L. and ASAKAWA, T. (1950). A comparison of certain aspects of body structure and body shape in 200 adults. Am. J. Phys. Anthropd. 8, 343-365.

ROBSON, J.R.K., BAZIN, M. and SODERSTROM, R. (1971). Ethnic differences in skinfold thickness. Am. J. Clin. Nutr. 24, 864-868.

ROCHE, A.F., SIERVOGEL, R.M., CHUMLEA, W.C. and WEBB, P. (1981). Grading body fatness from limited anthropometric data. Am. J. Clin. Nutr. 34, 2831-2838.

ROSE, G., HAMILTON, P.J.S., KEEN, H., REID, D.D., McCARTNEY, P. and JARRET, R.J. (1977). Myocardial ischaemia, risk factors and death from coronary heart disease. Lancet 1, 105-109.

ROSENBAUM, S. (1954). Heights and weights of the Army Intake, 1951. JL. R. Statist. Soc. A. 117, 331-347.

RYAN, A.F., JOINER, B.L. and RYAN, B.F. (1981). Minitab reference mannual. University Park, Pa: Pennsylania State University.

SATWANTI, K., BHARADWAJ, H. and SINGH, I.P. (1977). Relationship of body density to body measurements in young Punjabi women: Applicability of body composition prediction equations developed for women of European descent. Human Biol. 49, 203-213.

SENDROY, J.JR. and CECCHINI, L.P. (1954). The determination of human body surface area from height and weight. US Naval Med. Res. Inst. Bethesda Md. Res. Rpt. 12, 385-410.

SHELDON, W.H. (1940). Varieties of Human Physique. New York: Harper.

SIERVOGEL, R.M., ROCHE, A.F., HIMES, J.H., CHUMLEA, W.C. and McCAMMON, R. (1982). Subcutaneous fat distribution in males and females from 1 to 39 years of age. Am. J. Clin. Nutr. 36, 162-171.

SILVERSTONE, J.T. (1970). Obesity and social class. Psychother. Psychoso. 18, 226-230.

SIRI, W.E. (1956). Body composition from fluid spaces and density: analysis of methods. University of California Radiation Laboratory publication no. 3349.

SKERLJ, B., BROZEK, J. and HUNT, E.E. (1953). Subcutaneous fat and age changes in body build and body form in women. Am. J. Phys. Anthrop. n.s. 11, 277-600

SLOAN, A.W. (1967). Estimation of body fat in young men. J. Appl. Physiol. 23, 311-315.

SLOAN, A.W. and SHAPIRO, M. (1972). A comparison of skinfold measurements with three standard calipers. Human. Biol. 44, 29-36.

SOCIETY OF ACTUARIES (1959). Build and blood pressure study, vol. 2. Chicago, Society of Actuaries, pp 230-237.

SORENSEN, J.A., MAZESS, R.B., SMITH, E.L., CLARK, J.A. and CAMERON, J.R. (1968). Bone mineral content and bone diameter vs age in the radius and humerus of normal subjects. Bone mineral and body composition progress report. University of Wisconsin.

SORLIE, P., GORDON, T. and KANNEL, W.B. (1980). Body build and mortality. The Framingham Study. J.A.M.A. 243, 1823-1831.

STEINKAMP. R.C., COHEN, N.L., GAFFEY, W.R., McKEY, T., BRON, G., SIRI, W.E., SARGENT, T.W. and ISAAC, E. (1956). Measures of body fat and related factors in normal adults. J. chron. Dis. 18, 1279-1307.

SUZANNE, C. (1980). Aging, continuous changes of adulthood. In Human

Physical Growth and Maturation, pp 203-218, ed. Johnston, F.E., Roche, A.F. and Suzanne, C. London: Plenum Press

SUZANNE, C. (1971). Heredite des caracteres anthropologiques measurable. Bull. et Mem. Soc. d'Anthrop. Paris 7, 169-224.

SUZANNE, C. (1977). Individual age changes in morphological characteristics. J. Hum. Evol. 6, 181.

SUZANNE, C. (1974). Les changements morphologiques lies a l'age. L'Anthropolgie 78, 693-718.

TANNER, J.M. (1953). Growth of the human at the time of adolescence. Lect. Sci. Basis Med. 1, 308-363.

TANNER, J.M. (1965). Radiographic studies of body composition in children and adults. In Human Body Composition: Approaches and Applications. Symposia of the Society for the Study of Human Biology, Vol. III, London: Pergamon Press.

TANNER, J.M. (1974). Sequence and temp in the somatic changes in puberty. In Control of the Onset of Puberty pp 448-470. ed. Grumbach, M.M., Graue, G.D. and Mayer, F.E. New York: John Wiley & Sons

TANNER, J.M. (1981). A History of the Study of Human Growth. Cambridge: Cambridge University Press

TANNER, J.M., WHITEHOUSE, R.H. and TAKAISHI, M. (1966). Standards from birth to maturity for height, weight, height velocity and weight velocity; British children 1965. Arch. Dis. Child. 41, 454-613.

TAYLOR, W.L. and BEHNKE, A.R. (1961). Anthropometric comparison of muscular and obese men. J. Appl. Physiol. 16, 955-959.

VIERORDT, H. (1906). In Anatomische, Physiologische und Physikalische Daten und Tabellen zum Gebrauch fur Mediziner Jena: Fischer

VOLKMANN, A.W. (1906). Quoted by Widdowson (1965)

WATSON, P.E., WATSON, I.D. and BATT, R.D. (1979). Obesity Indices. Am. J. Clin. Nutr. 32, 736-737.

WEINER, J.S. and LOURIE, J.A. (1969). Human Biology: a guide to field methods 1BP Handbook no 9. Oxford: Blackwell Scientific Publications.

WEINER, J.S. and LOURIE, J.A. (1981). Practical Human Biology. London: Academic Press.

WELLS, J.B., PARIZKOVA, J. and JOKL, E. (1962). Exercise, excess fat and body weight. In Studies in Clinical Physiology of Exercise, VIII. 16, 35-40.

WELLS, J.B., PARIZKOVA, J. and JOKL, E. (1962). Fitness and fatness. In Studies in Clinical Physiology of Exercise VIII, 16, 3-7.

WELTMAN, A. and KATCH, V.L. (1978). A non population-specific method for predicting total body volume and percent fat. Human Biol. 50, 151-158.

WESSEL, J.A., UFER, A., VAN HUSS, W.D. and CEDER GUIST, D. (1963). Age trends of various components of body composition and functional characteristics in women aged 20-69 years. Ann. N.Y. Acad. Sci. 110 608-622.

WIDDOWSON, E.M. (1965). Chemical analysis of the body. In Human body composition, ed. Brozek, J. Symposia of the Society for the study of Human Biology, Vol VII. London: Pergamon Press.

WIDDOWSON, E.M., MCCANCE, R.A. and SPRAY, C.M. (1951). Chemical composition of the human body. Clin. Sci. 10, 113-125.

WILMER, H.A. (1940). Quantative growth of skin in relation to human surface area. Proc. Soc. exp. Biol. Med. 43, 386-388.

WILMORE, J.H. and BEHNKE, A.R. (1969). An anthropometric estimation of body density and lean body weight in young men. J. Appl. Physiol. 27, 25-31.

WILMORE, J.H. and BEHNKE, A.R. (1968). Predictability of lean body weight through anthropometric assessment in college men. J. Appl. Physiol. 25, 349-355.

WILMORE, J.H., GIRANDOLA, R.N. and MOODY, D.L. (1970). Validity of skinfold and girth assessment for predicting alterations in body composition. J. Appl. Physiol. 29, 313-317.

WOMERSLEY, J. (1974). Fat and fat free mass in man. PhD. Thesis Faculty of Science, Glasgow University

WOMERSLEY, J. and DURNIN, J. V. G. A. (1977). A comparison of the skinfold method with extent 'overweight' and various weight-height relationships in the assessment of obesity. Br. J. Nutr. 38, 271-284.

WOMERSLEY, J. and DURNIN J.V.G.A. (1973). An experimental study on variability of measurements of skinfold thickness on young adults. Human Biol. 45, 281-292.

WOMERSLEY, J., DURNIN, J.V.G.A., BODDY, K. and MAHAFFY, M. (1976). Influence of muscular development, obesity and age on the fat-free mass of adults. J. Appl. Physiol. 41, 223-229.

WOODWARD, K.T., RANDOLPH, C.L., JR., VAN HOEK, R., HARTGERING, J.B., CLAYPOOL, H.A., MANSKEY, A.A. and NOBLE, J.J. (1960). The Walter Reed body counting facility. Washington D.C., Walter Reed Army Insititute of Research.

YOUNG, C.M. and BLONDIN, J. (1962). Estimating body weight and fatness of young women. J. Am. Dietetic Assoc. 41, 452-455.

YOUNG, C.M., BLONDIN, J., TENSUAM, R. and FRYER, J.H. (1963). Body composition of 'older' women. J. Am. Dietetic Assoc. 43, 344-348.

Table 1A

APPENDIX A

Establishment	Location	Total Seen	No of Males	No of Females
Army Bases				
Kirknewton - QOH	Midlothian	243	243	-
Glencourse Barracks	Midlothian	90	90	-
Middle Wallop - AAC	Hampshire	140	140	-
CAD Kineaton - RAOC	Warwickshire	187	114	73
Guards Depot, Pirbright	Surrey	275	272	3
Gaerlochhead - RIR	Dunbarton	33	33	-
Catterick	N Yorkshire	116	30	86
Guilford	Surrey	98	-	98
Aldershot & Cambridge Military Hospital	Hampshire	420	224	196
Arborfield - REME	Berkshire	171	171	-
Woolwich Military Hospital	London	78	-	78
BAOR - Ösnabruch & Rhinedahlen	BAOR	313	264	49
	Totals	2,164	1,581	583

Table 2A

Establishment	Location	Total Seen	No of Males	No of Females
Navy Bases				
HMS Nelson	Hampshire	252	192	60
HMS Sultan	Hampshire	285	285	-
HMS Seahawk	Cornwall	412	360	52
HMS Collingwood	Hampshire	508	508	-
HMS Neptune	Dunbarton	146	100	46
Plymouth Bases	Devon	371	328	43
	Totals	1,974	1,773	201

Table 3A

Establishment	Location	Total Seen	No of Males	No of Females
RAF Bases				
RAF Linton-on-Ouze	Yorkshire	102	68	34
RAF Finningley	Yorkshire	118	98	20
RAF Buchan	Aberdeenshire	91	62	29
RAF Leuchars	Fife	124	105	19
RAF Lossiemouth	Morayshire	450	404	46
RAF St Athen	S Glamorgan	199	161	38

Establishment	Location	Total Seen	No of Males	No of Females
RAF Bases (cont)				
RAF Halton	Buckinghamshire	364	335	29
RAF Abingdon	Oxfordshire	192	180	12
RAF Hereford	Hereford	90	50	40
RAF Stafford	Staffordshire	242	181	61
RAF Kinloss	Morayshire	274	263	11
RAF Swinderby	Lincolnshire	168	168	-
	Totals	2,414	2,075	339

NOTE: Some Army personnel were examined at RAF Hereford.
Some RAF personnel were examined at Middle Wallop.

Total Females seen 1,123
Males seen 5,429

Civilian Sample: Description of the Number of People seen at each Location, and from each Company

Company	Location	MALES			FEMALES		
		Approx Total No	No Seen	% Seen	Approx Total No	No Seen	% Seen
Bank of Scotland	Glasgow	120	34	28	120	38	32
	Edinburgh		17	-		28	-
	London	130	35	27	290	72	25
British Rail	Glasgow	-	178		-	35	
Civil Service	Worthing	560	146	26	840	268	32
	London	750	52	7	750	47	6
MOD Civilians	Hampshire, Devon, SW England, Cardiff	-	8	-	-	18	-
Clydesdale Bank	Glasgow	474	22	5	347	58	17
University of Glasgow	Glasgow	-	23		-	31	
Hospital	Glasgow, Birmingham, Catterick	-	35		-	44	
DHSS	London	-	71		-	80	
Queens College	Glasgow	64	7	11	132	18	14
D Montgomery	Glasgow	156	8	5	50	25	50
Reo Stakis	Glasgow	43	7	16	97	11	11
Shell UK Ltd	Glasgow	130	16	12	130	12	9
Tennant Caledonian	Glasgow	579	10	2	320	15	5

Company	Location	MALES			FEMALES		
		Approx Total No	No Seen	% Seen	Approx Total No	No Seen	% Seen
Scottish Amicable	Glasgow	60	18	3	85	12	14
	Stirling	146	39	27	327	77	23
Royal Bank Of Scotland	Glasgow	15	-	-	31	18	58
	Edinburgh	37	21	57	73	17	23
Housewife	Glasgow	-	-	-	-	1	-
Local Transport	Birmingham		1	-	-	-	-
National Coal Board	Doncaster/ Sheffield	1,000	200	20	800	221	28
	Stoke-on-Trent	300	50	17	-	-	-
RAF Stafford Supply Depot	Stafford	500	68	14	500	63	13
Total Seen			1,066			1,209	

NOTE: 'Approx Total No' represents the approximate number of males or females at the individual offices or factories which were visited. It does not represent the number of people employed by the company in the entire city.

Army Sample: by Rank

Males

n = 1587

Rank	Total Nos	Sample Size	% Examined
Junior	—	322	
Private	55,470	516	1.0%
Lt Cpl	20,580	177	1.0%
Cpl	21,367	194	1.0%
Sgt	14,622	159	1.0%
S Sgt	7,304	63	1.0%
WO II	5,541	49	1.0%
WO I	2,143	24	1.0%
		+ 1 unknown rank	
O Cdt	–	1	–
2nd Lt	849	3	0.5%
Lt	1,729	16	1.0%
Cpt	4,769	28	0.5%
Major	5,253	23	0.5%
Lt Col	1,810	9	0.5%
Col	590	2	–
Other	336		
Total Army ORs	127,027	Sample 1,505	
Officers	15,336	82	
	142,363	1,587	

Army figures taken from 'Abstract of Army Manpower Statistics', No 88 1978/79
Strength by Age/Rank as at December 1978

RAF Sample: by Rank

Males

n = 2069

Rank	Total Nos	Sample Size	% Examined
Apprentice	514	-	-
Aircraftsman	6,021	418	7.0%
Leading AC	3,746	73	2.0%
Senior AC	18,292	338	2.0%
Junior Tech	7,841	193	2.5%
Corporal	15,889	351	2.0%
Sergeant	10,543	250	2.5%
Flight Sgt	2,531	59	2.5%
Chief Tech	3,626	84	2.5%
WO	2,271	42	2.0%
Pilot Officer	336	32	9.5%
Flying Officer	1,209	38	3.0%
Flight Lt	6,248	119	2.0%
Squadron Leader	3,716	55	1.5%
Wing Commander	1,340	15	1.0%
Group Captain	426	1	0.2%
Chaplain		1	
Others	585		
Total Airmen/Aircrew	71,274	Sample 1,808	
Officers	13,860	261	
	85,134	2,069	

RAF Figures from HQ RAFSC

Airmen: Numbers as at October 1980. Officers: Numbers as at July 1980.

Navy Sample: by Rank

Males

n = 1773

Rank	Total Nos	Sample Size	% Examined
Junior	2,884	81	3.0%
Ord/Rate) Able Rate)	20,576	97) 328)	2.0%
Leading Rate	9,673	196	2.0%
Petty Officer	8,581	442	5.0%
Chief PO	8,853	380	4.5%
Fleet CPO	800	27	3.0%
Midshipman	726	7	1.0%
Sub Lt	1,190	21	2.0%
Lt	2,866	86	3.0%
Lt Cdr	2,461	74	3.0%
Cdr	1,196	23	2.0%
Cpt	381	3	1.0%
Chaplain	99	4	4.0%
Commodore	23	1	4.5%
RM	644	3	0.5%
Other Ranks (Special duties Officers included)	113	-	

Total Naval Seamen	51,457	Sample	1,551
Officers	9,699		222
	61,156		1,773

RN Figures supplied by Stats Department, Travis House

Seamen: Numbers as at quarter ending March 1980. Officers: Numbers as at June 1980.

WRAC Sample: By Rank

Females

n = 583

Rank	Total Nos	Sample Size	% Examined
Private	2,884	364	12%
L/Cpl	888	61	7%
Cpl	585	42	7%
Sgt	346	31	9%
S/Sgt	73	3	4%
WO II	65	5	8%
WO I	20	1	5%
2nd Lt	72	7	10%
Lt	227	27	12%
Capt	151	26	17%
Major	159	13	8%
Lt Col	28	2	7%
Col	15	1	7%
Brig	2	-	-

Total WRAC & QARANC Servicewomen	4,861	Sample	506
Officers	854		76
	5,715		582

Figures taken from 'Abstract of Army Manpower Statistics', No 88, 1978/79

Table 9A

WRAF Sample: by Rank

Female

n = 339

Rank	Total Nos	Sample Size	% Examined
A/C	498	42	8%
LAC	717	47	7%
SAC	3,519	201	6%
JT	82	3	4%
Cpl	579	28	5%
Sgt	90	5	6%
Flt/Sgt	21	2	9%
WO	15	-	-
P/Off	124	6	5%
F/Off	151	3	2%
Flt/Lt	100	2	2%
Sqn Ldr	40	-	-
Wing Cdr	3	-	-
Gr Capt/A Cdr	3	-	-

Total Airwomen	5,521	Sample	328
Officers	421		11
	5,921		339

Figures supplied by HQ RAF SC as at October 1980

WRNS Sample: by Rank

Female

n = 201

Rank	Total Nos	Sample Size		% Examined
Jnr		1		
OR	1,754	34	122	7%
AR		87		
LR	710	45		6%
PO	270	16		6%
CPO	94	7		7%
FCPO	11	-		-
3rd Officer	131	4		3%
2nd Officer	113	5		4%
1st Officer	33	2		6%
Chief Officer	10			
Supt	3			
Cmdt	1			

Total WRNS	2,839	Sample	190
Officers	291		11
	3,130		201

Figures supplied by Stats Department, Tavis House, Quarter ending March 1980.

Army Sample: by Arm/Corps

Males

n = 1587

Arm/Corps	Total Soldiers	Sample	%	Total Officers	Sample	%
H Cav	1,368	31	2.5%	128	5	4.0%
RAC	8,366	37	0.5%	1,069	4	0.4%
RA	12,434	78	0.6%	1,460	4	0.3%
RE	12,059	38	0.3%	1,312	3	0.2%
R Sigs	11,137	39	0.3%	1,080	1	0.1%
Footguards	5,855	210	3.5%	454	3	0.7%
Infantry	27,994	461	1.5%	2,577	18	0.7%
Paras	2,305	34	1.5%	221	1	0.5%
SAS	49	-	-	5	-	-
AAC	852	18	2.0%	182	12	6.5%
RCT	8,286	25	0.3%	888	-	-
RAMC	2,501	37	1.5%	774	7	1.0%
RAOC	6,732	157	2.5%	1,066	2	0.2%
REME	13,776	265	2.0%	995	11	1.0%
RMP	2,029	1	0.1%	145	-	-
RAPC	1,701	9	0.5%	496	3	0.5%
RAVC	142	-	-	26	-	-
RMAS Band	42	-	-	1	-	-
SASC	94	-	-	21	-	-
MPSC	105	-	-	5	-	-

Arm/Corps	Total Soldiers	Sample	%	Total Officers	Sample	%
RADC	297	2	0.7%	178	1	0.2%
RPC	1,470	1	0.1%	95	-	-
Int Corps	907	-	-	244	-	0.4%
APTC	343	7	2.0%	37	1	2.5%
ACC	4,762	55	1.0%	158	-	-
GSC/RSC	51	-	-	-	-	-
LS List	532	-	-	-	-	-
Gen List	-	-	-	30	-	-
Staff	-	-	-	747	-	-
Bde of Gurkhas	-	-	-	153	-	-
RA CH d	-	-	-	173	1	0.5%
RAEC	-	-	-	571	5	1.0%
ALC	-	-	-	45	-	-
Total	126,189	1,505		15,336	82	

Strength by Arm/Corps as at 31 March 1979.

RAF Sample: by Trade/Occupation

Males - Airmen

n = 1808

Trade Group/ Occupation		Total Nos		Sample Size	% Examined
Airmen	Gp 1	18,977		777	4.0%
	2	6,060		131	2.0%
	3	4,936		72	1.5%
	5	3,646		121	3.5%
	6	4,399		84	2.0%
	7	269		-	-
	8	6,244		113	2.0%
	9	1,893		29	1.5%
	10	2,815		42	1.5%
	11	2,894		9	0.3%
	12	953		10	1.0%
	13	1,567		20	2.0%
	14	1,166		15	1.0%
	15	936		14	1.0%
	16	148		-	-
	17	3,674		39	1.0%
	18	5,408		200	3.5%
	19	3,580		47	1.5%
	21	293		2	0.1%
PMRAFNS		193		-	-
Aircrew		1,222		64	5.0%
		71,274	AIM	1	-
			Educator	1	-
			Recruits	5	-
			Mountain Rescue	2	-
				1,808	

NOTE: The trade groups, GP1-21, are as described in AP3392, Vol 2, Leaflet 402, Annex B.

Table 12A (b)

RAF Sample: by Occupation

Males: Officers

n = 261

Occupation	Total Nos		Sample Size	% Examined
GD/Pilot	4,221		53	1.5%
GD/Nav	2,094		72	3.5%
GD/AEO	353		13	4.0%
GD/Eng	54		-	-
GD/ALM	29		-	-
GD/G	1,033		-	-
P1	111		1	1.0%
Eng	2,345		23	1.0%
Supply	872		28	3.5%
Admin	1,686		22	1.5%
Systems	400		1	0.2%
Mar	37		-	-
Medical	444		6	1.5%
Dental	110		3	3.0%
Med Services	47		-	-
Chaplain	102		2	2.0%
Logistics	21		-	-
RAF Regt	-		1	-
Mus	8	Catering	2	-
Med T	25	ATC	9	-
	13,992	Education	12	-
		F Cont	8	-
		Unknown	5	-
			261	

Figures as at November 1980.

Table 13A (a)

Navy Sample: by Trade/Occupation

Males: Seamen

n = 1551

Trade/Occupation	Total Nos	Sample Size	% Examined
Manual	?	838	-
Technical	?	289	-
Logistical	?	343	-
Submariner	?	81	-
		1,551	

Table 13A (b)

Males: Officers

n = 222

Trade/Occupation	Total Nos	Sample Size	% Examined
Observers/Pilots	?	41	-
Seamen/Submariners	4,264**	43	1.0%
Engineer	2,682*	38	1.5%
Supply & Sec	813	29	3.5%
Instructor	653	58	9.0%
Medical	344	4	1.0%
Dental	106	2	2.0%
Chaplain	99	4	4.0%
Medical Services	47	-	-
Careers Services	47	-	-
Royal Marines	644	3	0.5%
	9,699	222	

* Includes six submariners
** Includes six submariners

WRAC Sample: by Trade/Occupation

OFFICERS

Trade/Occupation	Sample Size
Administration	6
Troop Leader	8
Nursing Officer	46
Nurse Tutor	12
Doctor	2
Pharmacist	1
Police	1

TOTAL = 76

OTHER RANKS

Trade/Occupation	Sample Size	Trade/Occupation	Sample Size
Recruit	77	Cook	24
Police	2	Data Telegraphist	4
Postal Service	1	Hairdresser	1
Administration	85	Ward Stewardess	17
Dental Branch	3	Waitress	19
Stores	3	Medical Technician	1
Medics	6	Tutor	2
PT Instructor	6	Platoon Sgt	3
Supply Spec	61	Accountant	3
Driver	21	Nurse	167

TOTAL = 506

Total WRAC Sample = 582

WRAF Sample: by Trade/Occupation

OFFICERS

Trade Group	Sample Size
Group 15	1
Group 18	2
Group 17*	5
Group 9	3

TOTAL = 11

OTHER RANKS

Trade Group	Sample Size	Trade Group	Sample Size
Group 1	4	Group 13	4
Group 2	5	Group 14	1
Group 3	-	Group 15	41
Group 5	3	Group 16	10
Group 6	8	Group 17*	50
Group 9	20	Group 18	115
Group 10	1	Group 19	17
Group 11	42	Recruit	7

TOTAL = 328

NOTE: Group 17*. It was assumed that all clerical staff belonged to Trade Group 17 (Accounting and Secretarial) as opposed to Group 10 (General Service).

Total WRAF Sample = 339

WRNS Sample: by Trade/Occupation Analysis

OFFICERS

Trade/Occupation	Sample Size
Medical	2
Administration	6
Radio Operator	1
Weapons Analyst	2

TOTAL = 11

OTHER RANKS

Trade/Occupation	Sample Size	Trade/Occupation	Sample Size
WEM	1	Stores	32
PT1	2	Dental	24
Medical	7	Cook	1
Met	8	Regulator	4
Aircraft Mech	2	Radio Operator	19
Administration	58	REM (A)	1
Stewardess	7	Radar	3
Air Weapons	1	Weapons Analyst	7
MT	8	Education	2
Photography	3		

TOTAL = 190

Total WRNS Sample = 201

APPENDIX B

Institute of Physiology

497, 612

Personnel Officer
Wodwich Military Hospital
LONDON

Dear

HEIGHT, WEIGHT AND BODY BUILD SURVEY

Further to our telephone conversation on the 10th August, I believe it would be helpful if I explain a little more about our survey, and our requirements.

Under the supervision of Prof. J.V.G.A. Durnin and based at Glasgow University, Miss Cheryl Webster and myself are setting up new 'Recommended Weight for Height' charts for the use of MOD. We have already visited over 20 camps from all three services, in order to collect data for these tables. All the information we collect is analysed by us at the University, and only the finished result is given to MOD, therefore each individual's results are completely confidential.

The measurements we take are height, weight, 4 bne measurements 4 circumferences to assess build and four skinfolds to assess 'fatness'.

We would like to visit your unit from the evening of Sunday 18th October until the morning of Saturday 24th October and if accommodation could be found for us in the Officers Mess we would be most grateful. If you wish me to write to the PMC, then please say. If there is no accommodation available, then we shall find our own locally.

We can see about twelve people in an hour and will work whichever hours best suit you and those who come along to be measured.

As we bring all our own equipment the only requirement we have is a room with two tables, a couple of chairs and an area for the subjects to get changed.

We would like to see as many females as possible, both civilian and non-civilian of all ages, ranks and jobs. Any males we see, however, we would prefer to be over 25 years old.

I hope that this is sufficient information, but if not, either myself or Miss Webster, can be contacted at the above number, Ext 497 or Ext 612.

Yours Sincerely

Miss Francis MacKay
RESEARCH ASSISTANT

APPENDIX C

UNIVERSITY OF GLASGOW

TEL: 041-339 8855
EXT. 612

THE UNIVERSITY,
GLASGOW, G12 8QQ.

Ref. FMcK/SL

, Esq.,
DHSS,
Midlands Region,
Five Ways Tower,
Frederick Road,
Edgbaston,
BIRMINGHAM B15 1ST

Dear Mr ,

I am writing concerning a 'Height, Weight and Fatness' survey being carried out in our institute under the supervision of Professor J.V.G.A. Durnin, on behalf of the Ministry of Defence. Mr. John Roberts, from Alexander Fleming House, London, gave me your name, and I believe that he has mentioned the project to you. Since I do not know how much he has explained, I shall give you some of the details.

I have, in fact, been in touch with Mr , A/Regional Controller, from Five Ways Tower, as his name was given to me by the Civil Service Medical Branch. Perhaps you could liase with him in considering the feasibility of carrying out this work.

The project is concerned with an attempt to set up new standards relating weight to height for men and women of various ages and body-builds which would be relevant to the adult population of the U.K.

We are undertaking this project because the tables which are in general use in this country - which indicate the weight that a person ought to be for a certain height, and which can be seen on many weighing machines or in chemist's shops - are really not relevant to the population of the U.K. They have been derived from insurance statistics on American men and women, most of them in the early part of this century, and often obtained in a very haphazard and inaccurate fashion. By careful measurements on several thousand adults scattered throughout several regions in Scotland, England and Wales, we hope to assemble tables showing the desirable weight which a person should have for his or her weight, and taking into account the basic body-build.

Such tables will be of use, of course, not only to doctors in their medical practice or in hospitals but also to individuals who wish to check on their weight and to obese people in assessing their degree of overweight. To assemble the tables properly will need measurements from about 12,000-15,000 adults in all, selected from different occupations, areas, social and age groups.

Because of all these specifications, we are hoping that large employers of labour, like yourself, will allow us access to their employees, in order to ask for volunteers.

APPENDIX D

WOULD YOU SPARE 10 MINUTES TO HELP MEDICAL RESEARCH?

We are carrying out a survey, covering the whole country, to obtain better information on the desirable weight men and women should have for their height. This will provide a most important guide for doctors in assessing not only obesity, but also many other medical conditions.

To do our research correctly we need to measure several thousand men and women, of all ages and builds. We would therefore be very grateful if you will help us and volunteer.

The measurements we take are:

(1) HEIGHT **(2) WEIGHT**

(3) SKINFOLDS: Upper arm, back, and waist

(4) LIMB GIRTHS: Upper arm, hips, leg and calf

(5) BONE DIAMETERS: Shoulders, hips, knee, and wrist.

After taking these measurements, we shall be happy, if you wish, to calculate your personal 'desirable' weight taking into account your height and build. All this information is confidential and your name and address are not required. In order to ensure the accuracy of these measurements, they are carried out with volunteers dressed partly in underwear or light sports clothing.

Professor J.V.G.A. Durnin

Frances McKay, B.Sc.

Cheryll Webster, B.Sc.

For further information please contact:

Appendix E

UNIVERSITY OF GLASGOW
Institute of Physiology
THE UNIVERSITY
GLASGOW, G12 8QQ.

TEL: 041-339 8855
EXT. 612

Ref. CW/MMcG

1st November 1982

Dear Sir

I recently visited your place of work in order to carry out a Height/Weight Survey. I am now interested in the percentage of people who volunteered. I would, therefore, be most grateful if you could possibly send me the total numbers of both Males and Females, separately, who are employed within your Branch and/or Organisation.

Thank you once again.

Yours sincerely

Research Assistant to
Professor J.V.G.A. Durnin

IN CONFIDENCE

Appendix F(1)

Office use only

Date:

Time:

Int:

C.W.N:

Y.Bl.B:

E.G:

1. Surname

2. Date of entry to Service ______________ mth ______________ yr

3. Place(s) of residence over the first 15 years of your life (town and county only)

Place 1	Place 2	Place 3

4. Do you live 'IN'? (Mess/Billets)
Please put a tick in relevant box YES ☐ NO ☐

5. Are you married? YES ☐ NO ☐

6. Date of Birth ______________ day ______________ mth ______________ yr

7. Age last Birthday ______________ yrs

8. Place of Birth (town and county) ______________

9. Place of Birth of father: ______________

" " of mother: ______________

10. Which Corps/Regt do you belong to? ______________

11. Present rank ______________

12. Present trade ______________

13. No. of years in this type of job ______________

14. If you have been in the Services for less than 6 months please answer the following questions:

a. Trade/Occupation before joining the Services?

____

b. No. of years?

____

15. Have you ever smoked cigarettes? YES ☐ NO ☐

16. If Yes, for how long? ______ yrs

17. How many cigarettes per day?

less than 5	☐	26 - 30	☐
6 - 10	☐	31 - 35	☐
111- 15	☐	36 - 40	☐
16 - 20	☐	41 - 45	☐
21 - 25	☐	more than 45	☐

18. Do you still smoke cigarettes? YES ☐ NO ☐

19. If NO, when did you stop?

Continued

20. Over the past 6 months has your weight been: steady ☐ rising ☐ falling ☐

21. Do you take any medicines or pills regularly? YES ☐ NO ☐

If Yes, please give details:

22. Is there anything else which might affect your weight YES ☐ NO ☐

If Yes, please give details:

---

23. How many times a week do you take exercise i.e. P.T. or sport?

Daily ☐
Twice a week or more ☐
Less than twice a week ☐
Only occasionally/never ☐

24. For how long have you maintained this level of exercise/lack of exercise? ________mt

25. Do you play any sport? YES ☐ NO ☐

If Yes, please specify:

26. Over the past few weeks, have you had to cut down on your normal activity due to illness or injury?

YES ☐ NO ☐

If Yes, please give details:

Civilian Questionnaire

IN CONFIDENCE

Appendix F(2)

1. Place(s) of residence over the first 15 years of your life (town and county only) Place 1 ______ Place 2 ______ Place 3 ______ No of years ____ No of years ____ No of years ____	Date: Am/Pm: C.W.N: Y.Bl.B:

2. Are you married? YES ☐ NO ☐

3. Date of Birth ______day______month ______year

4. Age last Birthday ______yrs

5. Place of Birth (town and county) ______

Place of Birth of father: ______

Place of Birth of mother: ______

6. Name of the firm which employs you ______

7. Occupation ______

8. Number of years in this occupation ______yrs

9. If you have held this post for less than 6 months, please state:

a. Previous occupation ______

b. Number of years ______yrs

10. Have you ever smoked cigarettes? YES ☐ NO ☐

11. If Yes, please state for how long: ______yrs

12. How many cigarettes per day?

less than 5	☐	26 - 30	☐
6 - 10	☐	31 - 35	☐
11 - 15	☐	36 - 40	☐
16 - 20	☐	41 - 45	☐
21 - 25	☐	More than 45	☐

13. Do you still smoke cigarettes? YES ☐ NO ☐

14. If No, when did you stop?

Continued

15. Over the past 6 months has your weight been:

- steady ☐
- rising ☐
- falling ☐

16. Do you take any medicines or pills regularly? YES ☐ NO ☐

If Yes, please give details:

17. Is there anything else which might affect your weight? YES ☐ NO ☐

If Yes, please give details:

---

18. How many times a week do you take exercise i.e. P.T. or sport?

- Daily ☐
- twice a week or more ☐
- less than twice a week ☐
- Only occasionally/never ☐

19. For how long have you maintained this level of exercise/lack of exercise? ________ mth

20. Do you play sport? YES ☐ NO ☐

If Yes, please specify:

21. Over the past few weeks, have you had to cut down on your normal activity due to illness or injury? YES ☐ NO ☐

If Yes, please give details:

Appendix G

Body Composition Data

	VARIABLE	NO.
Subject	4	1
Card No. [1]	5	
Geographical Area	7	2
Sex (M/F)	8	3
Civilian/Non Civilian (C/N)	9	4
Social Class	11	5
Examination Date (DAY MTH YR)	17	6
Date of Birth (DAY MTH YR)	23	7
Age (yrs)	25	8
Height	29	9
Weight	33	10
Skinfolds (mm) Biceps	36	11
Triceps	39	12
Subscapular	42	13
Supra-iliac	45	14
Total Skinfolds	49	15
% Fat	52	16
Fat Free Mass (kg)	55	17
Circumferences (cm) Calf	58	18
Thigh	61	19
Buttocks	65	20
Upper Arm	68	21
Diameters (cm) Ulna	70	22
Tibia	73	23
Biacromial	76	24
Biiliac	79	25
	80	26

Subject No.		4	
Card No.	2	5	
Time/Interviewer (F=1; S=2)		7	27
Ethnic Group		88	28
Date of Entry	MTH YR	12	29
M/S (M=2; S=1)		13	30
Corps/Regt/Employment		17	31
Location		20	32
Rank		23	33
Trade/Occupation		26	34
No. of Months	MTH'S	29	35
Previous job		32	36
No. of Months		35	37
Smoke?		38	38
No. of cigarettes		41	39
Still smoke?		45	40
Weight change?		48	41
Medication		51	42
Other factors		54	43
Exercise frequency		57	44
No. of months	MTH'S	60	45
Sport(s)		64	46
Illness		67	47
Live in/out		70	48

FMcK/SL

Appendix H

Computer Variables

The following section describes the variables on the computer sheet which originated from the questionnaire. It also includes the reasons behind the questions and the choice of answers. The total number of variables, from the questionnaire and anthropometric data, was 48.

Subject Number (Variable 1)

Geographical Area (Variable 2)

This was defined as the Region in which the subject lived during the first ten years of his life or if he moved when under ten years old, the Region in which he spent most of his first fifteen years biased towards his early years. If he had moved between many regions spending less than five years in any one region, he was coded as SCOTTISH, WELSH, ENGLISH, IRISH or NON-BRITISH, as was relevant.

Subjects, mainly from Forces families, who had travelled a lot throughout Britain or Forces bases abroad, were coded as BRITISH -NO- AREA. Codes between 0 and 99 were given to the following categories and areas:

Missing Answer

SCOTLAND
ENGLAND
N. IRELAND

ANTRIM
ARMAGH
AVON
BEDFORDSHIRE
BERKSHIRE
BORDERS
BUCKINGHAMSHIRE
CAMBRIDGESHIRE
CENTRAL
CHESHIRE
CLEVELAND
CLWYD
CORNWALL & ISLES OF SCILLY
CUMBRIA
DERBYSHIRE
DEVON
DORSET
DOWN
DUMFRIESS & GALLOWAY
DURHAM
DYFED
ESSEX
FERMANAGH
FIFE
GLAMORGAN

Non-British

WALES
S. IRELAND
BRITISH-NO-AREA

ISLE OF MAN
ISLE OF WIGHT
KENT/LANCASHIRE
LEICESTERSHIRE
LINCOLNSHIRE
LONDON
LONDONDERRY
LOTHIAN
MANCHESTER
MERSEYSIDE
NORFOLK
NORHTAMPTONSHIRE
NORTHUMBERLAND
NOTTINGHAM
ORKNEYS
OXFORDSHIRE
POWYS
SHROPSHIRE
SHETLAND
SOMERSET
STAFFORDSHIRE
STRATHCLYDE
SUFFOLK
SURREY
SUSSEX: East/West

Appendix H (contd)

GLAMORGAN : MID/SOUTH/WEST
GLOUCESTERSHIRE
GRAMPIAN
GWENT
GWYNEDD
HAMPSHIRE
HEREFORD AND WORCESTER
HERTFORDSHIRE
HIGHLAND
HUMBERSIDE

TAYSIDE
TYNE AND WEAR
TYRONE
WARWICKSHIRE
WESTERN ISLES
WEST MIDLANDS
WILTSHIRE
YORKSHIRE: North/South/West

Male/Female (Variable 3)

Male Code　　　　　　　　Female Code

Civilian/Non-Civilian (Variable 4)

Civilian Code　　　　　　　　Non-Civilian Code

Work Background

Social Class (Variable 5)

FORCES: All forces personnel were coded as '99' because social class coding was not applicable

CIVILIANS: Civilians werecoded as per the Classification of Occupations 1970' produced by the Office of Population Censuses and Surveys, but using a modified class grouping.

OPCS Social Classes	Social Classes used in this Survey
I Professional, etc. occupations II Intermediate occupations	I
III Skilled occupations (N) Non-manual	II
III Skilled occupations (M) Manual IV Partly skilled occupations	III
V Unskilled occupations	IV

Examination Date: (Variable 6)

Date of Birth: (Variable 7)

Age: (Variable 8)

Geographical Background (Variable 26)

This variable indicated whether or not the subject and his family had lived in the geographical area coded in variable 2, for at least one generation.

Categories

1. Subject was born and brought up in the same region as both his parents were born in
2. Subject was not born in the same region as both of his parents.

Time/Interviewer (Variable 27)

This variable recorded whether the measurements were taken in the morning or in the afternoon, and who the examiner was.

Ethnic Group (Variable 28)

We wish to select for analysis only those subjects who were white caucasians, i.e. of European or white descent. Ethnic group was determind from the combination of skin colour, surname and the place of birth of both the subject and the subject's parents. The measurements from subjects whose ethnic group was outwith our specifications were never used in the statistical analysis. From the remaining acceptable ethnic groups, only those who had spent the first 15 years of their life in Britain or in the Forces bases were included in the analysis. (i.e. if their Geographical Area code was British).

N.B. In this context the word'British' includes the whole of Ireland.

Date of Entry (Variable 29)

This variable recorded the date of entry to the Armed Forces. For the Civilian Sample this variable had a 'missing valve' code.

Married/Single (Variable 30)

Married category included people who were separated. Single category included people who were divorced.

Corps/Regiment/Employer (Variable 31)

Thsi variable coded either the branch of the Forces subject belonged to, or in the case of the Civilian subjects, what type of company or Establishment employed him.

The following categories were used for the Forces Sample:

RAF

WRAF
RAF REGIMENT
RAF AUSTRALIAN

NAVY

WRNS
MARINES
NAVY - AUSTRALIAN

ARMY

RAEC	ACC	APTC
INFANTRY	RAMC	RADC
REME	PARA. REGT.	RAVC
RA	RMP	MPSC
RE	RAPC	SASC
R. SIGNALS	H. CAVALRY	Ra Ch D
RAC	INT. CORPS.	GSC/RSC
RCT	AAC	SAS
RAOC	LS LIST	WRAC
FOOTGUARDS	RPC	QARANC

The following categories were used for the Civilian Sample:

Unemployed
School Leaver
Civil Service
Housewife
Hospital
Local Bus Company
College/University
Tennant Caledonain Breweries
Shell UK Ltd
British Rail
Self Employed
Small Company

Reo Stakis Organisation
Daniel Montgomery Ltd
Marks & Spencers Ltd
NCB
DHSS
Royal Bank of Scotland
Clydesdale Bank
Bank of Scotland
Civil Service other than MOD and DHSS
Employed by an individual

Location (Variable 32)

This variable,coded the location at which the measurements were taken. For Forces personnel, each camp was given a code, as shown below. With civilians, the location was coded using the geographical area code list from Variable 2.

Location - Army

Ritchie Camp (Midlothian)
Glencourse (Edinburgh)
Garelochhead (Strathclyde)
Bradbury Lines(Hereford)
Pirbright(Surrey)
Aldershot(Hants)
CAD Kineaton(Warwick)
Guilford(Surrey)
Middle Wallop (Hants)
Catterick (Yorks)
Woolwich(G. London)
Arborfield(Berks)

RAF

Kinloss (Grampian)
Lossiemouth (Grampian)
Halton (Bucks)
Hereford (Hereford)
Swinderby (Lincs)
Stafford (Staffs)
ST. Athen (S. Glam)
Abingdon (Oxfordshire)
Leuchars (Fife)
Buchan (Grampian)
Finningley (Yorks)
Linton-on-Ouze (N. Yorks)

Navy

HMS Collingwood (Hants)

HMS Seahawk (Cornwall)

HMS Nelson (Hants)

HMS Sultan (Hants)

HMS Neptune (Strathclyde)

HMS Drake (Devon)

BAOR

Ösnabruck
Rhinedahlen

Ranks (Variable 33)

The following ranks were coded for each service:

ARMY & MARINES	RAF	NAVY
JUNIOR	JUNIOR	JUNIOR
PRIVATE	A/C	ORD RATE
L/CORPORAL	LAC	ABLE RATE
CORPORAL	SAC	LEADING RATE
SERGEANT - S/SERGEANT	J. TECH	P.O.
WO II	S. TECH	C.P.O.
WO I	CORPORAL	F.C.P.O.
POTENTIAL OFFICER	SERGEANT	MIDSHIPMAN
2nd LT	FLT/SERGEANT	SUB LIEUTENANT
LT	C. TECH	LIEUTENANT
CAPTAIN	WO	LIEUTENANT CDR
MAJOR	MEAO	COMMANDER
LT COLONEL	P. OFFICER	CAPTAIN
COLONEL	FLYING OFFICER	CHAPLAIN
BRIGADIER	FLT	COMMODORE
	LIEUTENANT	
	SQUADRON LEADER	
	WING COMMANDER	
	CHAPLAIN	
	GROUP CAPTAIN	

Civilians

Rank was given a 'missing value' code.

Trade/Occupation(Variable 34)

An extensive list of trades and occupations was produced for all the separate units within the Armed Forces. A similar list was also produced for the various occupations in the Civilian Companies included in this survey. See Appendix K.

Number of Months (Variable 35)

This variable recorded the length of time the subject had spent in his trade or occupation.

Previous Job/Number of Months (Variable 36 & 37)

These variables were disregarded unless the subject had changed his occupation within the six months prior to examination. If his job had changed the S.C. of the previous job was coded as Variable 36, and the number of months in the job as Variable 37.

SMOKING HABITS

Smoke (Variable 38)

This variable recorded whether the subject had ever smoked and if so, for what length of time. If the subject was a non-smoker then variables 38, 39 and 40 were coded as such.

No. of cigarettes (Variable 39)

This variable recorded the approximate number of cigarettes smoked per day. The following categories were given:

Less than 5	26 - 30
6 - 10	31 - 35
11 - 15	36 - 40
16 - 20	41 - 45
21 - 25	more than 45

(see 'Questionnaire' chapter, note on charges to questionnaire)

Still Smoke (Variable 40)

This variable showed whether the subject had given up smoking or still smoked cigarettes. If the former, then the date at which he gave up smoking was recorded on the data sheet.

Health Factors

Weight Change (Variable 41)

This variable was used to record whether the subjects weight, over the previous six months had been (a) steady (b) rising or (c) falling.

Medication (Variable 42)

This variable was used to detect any subjects who were taking drugs which may have affected the 'make up' of the fat component of the body, and therefore affect the accuracy of predicting percentage body fat from the skinfold measurements.

Factors Affecting Weight (Variable 43)

This variable gave the subject the opportunity to give an explanation for the fact that they perhaps answered either (b) or (c) to Variable 41.

Factor:

Diet
Pregnancy
Operation
Illness
Stopped smoking
Worry/Domestic problems
Miscarraige
Gastractomy
Hormone Imbalance
Diabetic
Spleen removed
Miscellaneous
Shifts/Overwork
Kidney malfunction
Leg/Knee injury
Bad Back
Thyroid troible
Apronectomy
Renal Glycosuria
Partial Gastrectomy
Growth Hormone treatment
Laporotomy
Glandular Illness
Hay Fever
Hysterectomy
Brain Operation

EXERCISE HABITS

Exercise Frequency (Variable 44)

A choice of four categories was given for this:

(a) Daily exercise
(b) Twice a week of more
(c) Less than twice a week
(d) Occasionally / Never

Length of Time (Variable 45)

This variable recorded the number of months or years that the subject had maintained the level of exercise chosen in Variable 44.

Sport (Variable 46)

This variable coded either one or in some cases, two sports, which were played most often.

Illness (Variable 47)

If the subject for any reason, had to cut down on his normal activity, then this variable recorded the cause.

Illnesses and Injuries coded were:

Injured leg
Injured chest
Flu
Other bacterial/viral infection
Injured arm/hand
Injured back
Cold
Stomach
Injured ribs

Facial Injury
Head Injury
Tuberculosis
Minor Operations
Miscarraige
Heart
Diabetic
Migraines
Renal Haematuria
Aneurysm
Crown's Disease

Allergy
Tonsillitis
Hypertension
Ulcer
Arthritis
Sinus
Asthma
Glandular Illness
Vasectomy

Hospital cases:

Chest
Leg
Whipples Disease
Virus
Heart Operation
Miscellaneous Operation

Motor cycle car crash
Miscellaneous (neither injury nor illness - unknown)
Appendix removed
Kidney Operation
Neuralgia

Live - In (Variable 48)

This variable recorded whether the subject lived in a Forces Mess/ Barracks or lived out. For civilians a 'missing value' code was used.

FORCES OCCUPATIONS	CIVILIAN EQUIVALENT	SOCIAL CLASS OPCS	SOCIAL CLASS Durnin
Mechanic/Technicians - all	Mechanics/Tech. workers	III (m)	III
Electricians - all types	Electricians	III (m)	III
Engineers - all types (not prof.) + fitters	Engineer and Allied Trades (not prof.)	III (m)	III
Non-Officers Eng/Elec Instructors	Technical Instructors	II	I
Eng. Officers - all types	Engineer - professional	I	I
Medical Sevices incl. M.Assistant, Radiog. etc.	Medical and related	II+I	I
Dentists + Dental Nurses + Hygenists	Dentists, Nurses, Med. workers	I+II	I
Cooks + chefs	Cook	III (m)	III
Steward/Stewardess	Waiter/ress	IV	III
Catering Officer/NCO	Manager - Restaurateur	II	I
Stores/supplies	Warehousemen, storekeepers	III(m)+IV	III
Admin + writers + clerks + accounts	Clerks, secretaries, cashiers	III (nm)	II
Silverman	Silverman	V	IV
Barman	Barman	IV	III
Tailor	Tailor	III (m)	III
Hairdresser	Hairdresser	III (m)	III
Policeman/Regulator	Policeman	III (nm)	II
Fireman	Fireman	III (m)	III
Recruit/Holdee	N/A	-	-
Physical Training Inst.	Sportsman	III (m)	III
Musician/Bandsman	Musician/Bandsman	II	I
Postal Service	Postmen - Mail sorters	IV	III

FORCES OCUPATIONS	CIVILIAN EQUIVALENT	SOCIAL CLASS OPCS	SOCIAL CLASS Durnin
Recruiting/Public Info.	Service, sport, recreational workers	IV	III
Chaplain	Clergy	I	I
Photographic Dept.	Industrial photographer/ employee	IV	III
Telephonist	Telephonist	IV	III
Tele-comms Operator	Telep. + Radio Op.	III (nm)	II
Telegraphist - all types Teleprinter Op.	Telegraphist	III (nm)	II
Radio Op./signaller	Radio Operator	III (nm)	II
Fighter Controller Air Traffic Controller/Radio Op.	Traffic Contollers	III (nm)	II
Radio Tech., powerman, Lineman	Tech., repairman, Linesman	III (m)	III
Weapons Analyst	?	III (nm)	II
Metalsmith	Metal worker (sheet).	III (m)	III
Gun Fitter/Armourer	Trade Craftsman	III (m)	III
Draughtsman/Design Ass.	Draughtsman	III (nm)	II
Bricklayer	Bricklayer	III (m)	III
Plummer	Plummer	III (m)	III
Carpenter	Carpenter	III (m)	III
Mountain Rescue	Sportsman + related	III (m)	III
Driver	Driver	III (m)	III
All Instructors	Teachers	II	I
Observer/Navigator	Navigator	II	I
Pilot	Pilot	II	I
Aircrew (not Eng.)	Tech. workers	III (m)	III
Meteorologist	Meteorologist	I	I
Infanteer	-	V	IV
Paratrooper	-	V	IV
Gunner - gun number	-	V	IV

FORCES OCCUPATIONS	CIVILIAN EQUIVALENT	SOCIAL CLASS OPCS	SOCIAL CLASS Durnin
Gunner - Tara	-	IV	III
Gunner - Op.	-	IV	III
Paratrooper - postal service	-	IV	III
Buffer	-	V	IV
Seaman - all types	Deck + Eng. room ratings	IV	III
Pioneer	Woodworkers	III (m)	III
Mortar man	-	IV	III
Surveyor - prof.	Surveyor	I	I
Accountant - prof.	Accountant	I	I
Exec. Officer	Manager	II	I
Guardsman - Technical	Technical worker	III (m)	III
Guardsman mounted	-	IV	III

APPENDIX J

Sedentary Trades: Civilians

MALES	FEMALES
General Clerk	General Clerkess
Administrator	Administrator
Manager	Manager
Bank Teller	Bank Teller
Computer Operator	Data Processor
	Secretary
	Computer Operator

Sedentary Occupations:Forces

MALES	FEMALES
Administrators (Army, Navy RAF)	Administrators (all ranks) } all three services
Supply Clerks (Army RAF)	Chemical workers } all three services
Air Traffic Controllers (RAF)	
Radio Operators (Army, Navy, RAF)	
Radar Operators (Army, Navy, RAF)	
Telegraphist (Army, RAF)	
Signaller (Army)	

Active Occupations: Forces

MALES	FEMALES
Infanteers(Army)	Nurses (all ranks) } all three services
Parachutists(Army)	Auxillary Nurses } all three services
P. T. Instructors (Army, Navy, RAF)	
Recruits(Army)	

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