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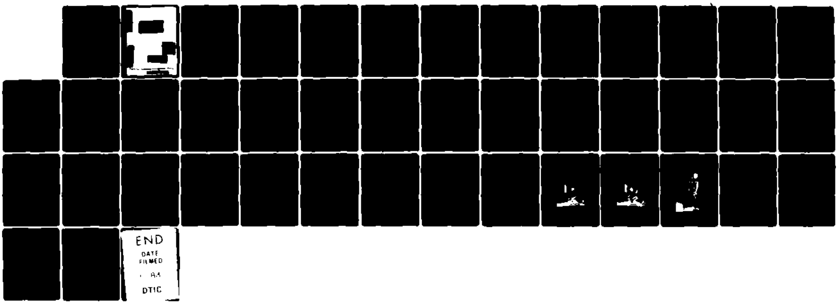

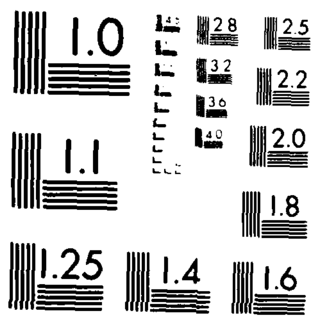

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RELATIONSHIP BETWEEN ANTHROPOMETRIC AND STRENGTH MEASUREMENTS OF CANADIAN FORCES PERSONNEL.

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ABSTRACT

In support of the development of occupational physical selection standards (OPSS) for Canadian Forces (CF) trades, the relationships between anthropometric parameters and static and dynamic strength tests were investigated. Data were collected from 335 CF males and analysis included calculation of simple correlation coefficients between strength and direct measures of anthropometry as well as derived ratios. Regression equations were also generated for both the static and the dynamic strength tests. The results revealed low correlations between anthropometry and these particular strength tests. As a result, the usefulness of these relationships for predictive purposes for OPSS is questionable.

INTRODUCTION

A survey of 369 Canadian Forces (CF) personnel (335 males and 34 females) was conducted at CFB Portage La Prairie in May 1980. Anthropometric data and two types of strength data were gathered for three separate projects; (a) comparison of the 15 inch pull test with other static strength tests, (b) the examination of dynamic strength measures as possible indicators of overall fitness, and, (c) the examination of anthropometric measures as possible predictors of strength and performance (see Appendices 4 and 5 for definitions). The static strength tests and equipment were developed by the US Army for potential use in Armed Forces recruiting stations (Appendix 5). The use of these tests and equipment were for the purpose of equipment reliability testing. The dynamic strength testing was performed to evaluate fitness levels of the base personnel, as part of a longitudinal study which began in 1975.

This report focuses on the relationship between specific anthropometric parameters and static and dynamic strength tests. If a strong relationship between these parameters can be demonstrated, the results could be used in support of the development of occupational physical selection standards (OPSS) to preselect recruits for physically demanding trades in the CF.

REVIEW OF LITERATURE

A review of the literature dealing with anthropometry and strength has revealed conflicting results. Variations in experimental design and type of subjects used account for most of the inconsistencies between studies. In addition, there are many factors, other than anthropometry, that have been shown to affect strength. These factors include age, gender, degree of fatigue, state of training, familiarity with the task and emotional state (motivation). Many studies which have attempted to establish relationships between anthropometry and strength fail to account for the influence of these other factors. Nonetheless, the literature has demonstrated that positive correlations between direct and derived anthropometric parameters and various body strengths are possible.

A positive correlation between strength and body weight has been reported in some studies. Roberts et al.(1) found that body weight was significantly related to elbow flexion strength and elbow extension strength, with correlation coefficients of 0.47 and 0.68, respectively. In a study of males aged 17-18, Watson and O'Donovan (2) reported a correlation of r=0.76 between body weight and a strength index composed of grip and back strength. Laubach and McConville (3) found that while the correlation between weight and hip flexion strength was r=0.63, a correlation of only r=0.18 existed between weight and hip extension strength. Some investigators have used body weight in conjunction with other measures and found higher correlations. Lamphiear and Montoye (4) found that a combination of weight, height, biacromial diameter, upper arm girth, and triceps skinfold accounted for most of the variation in back and grip strength.

Most anthropometric measurements are grouped as being either girth dimensions or linear dimensions. Girth measures were found to be superior to linear measures in their relationship to strength (1,3,5). Clarke (5) reported a correlation coefficient of 0.63 between leg strength and thigh girth, as opposed to 0.31 between leg strength and leg length. Roberts et al. (1) found that elbow flexion strength was highly dependent on the girths of the lower and upper arm and not at all on upper arm length. Grip strength, however, was found to be more related to length of the forearm than to its girth. Roberts et al. (1) attributed this discrepancy, in part, to the fixed grip setting of the hand dynamometer. Laubach and McConville (6) found that of the 23 anthropometric variables used in their study, measures of body girths such as shoulder, chest and thigh circumference, correlated best with measures of hip and trunk strength. In a study of school girls aged 8-16, Maglischo (7) pointed out that in young children, length measures as well as girth measures were effective predictors of strength. At these ages, increases in body weight, strength and linear growth are all occurring proportionately. However, in older children and young adults, strength may continue to increase for some time after augmentations in body weight and linear growth have stopped. Therefore, girth measures, as related to muscular development, may be more appropriate for adults.

The prediction of strength from skinfold measures and lean body mass has met with varying degrees of success. Clarke (5) found that the correlations of skinfold measures over the abdomen and ilium with 16 strength tests of the trunk, legs and arms were generally low, ranging from r= -0.02 - 0.45. In all but one instance, strength was more highly correlated with body weight than with skinfold measures. Laubach and McConville (3), in a study of 45 males aged 17-35, found that measures of trunk and hip strength yielded insignificant correlations with several skinfold measures. It was found that skinfold measures of the triceps, subscapular, suprailiac, juxta nipple, mid axillary line, xiphoid and suprapatella regions by themselves produced insignificant correlations, with the highest being r=0.22 for trunk flexion strength with triceps skinfold. The calculation of lean body mass resulted in a correlation coefficient of 0.69 with hip flexion strength. Lean body mass, however, presented no significant advantage over the use of body weight as a criterion for comparing the strength of the trunk and hips. In a further study using 77 subjects aged 17-39, Laubach and McConville (6) again found that lean body mass was a better predictor of strength than skinfold measures, but no better than body weight. In this second study, it was concluded that both body weight and lean body mass were ineffective predictors of strength.

Derived calculations such as thigh volume, muscle volume and bone volume were found by Watson and O'Donovan (2) to be more highly related to grip and back strength than direct measures of the lower limb. These derived measures accounted for an additional 3 to 9 % of the variance in strength. In two other studies, however, Thorsen (8) and Smith and Royce (9) indicated that limb volumes and segment areas did not correlate as well with leg strength as did body weight, lean body weight and length measures.

Another common index used to predict strength is somatotype. Jones (10) found that mesomorphy (predominance of muscle tissue) correlated reasonably well (r=0.61) with measures of arm, shoulder and leg strength. High correlations, however, were not found in later studies. Thorsen (8) reported that body weight correlated more highly with strength of the legs and back than did measures of mesomorphy. Similarly, Watson and O'Donovan (2) obtained a coefficients of 0.50 between mesomorphy and grip and back strength, as opposed to 0.76 for body weight and these strengths.

The literature revealed that many studies have been devoted to establishing relationships between various anthropometric and strength parameters. DCIEM's purpose in this study was to conduct an investigation further to the evidence that strong correlations between these parameters are possible. The particular variables selected were tested for potential future use as part of the selection process for CF trades personnel.

METHODS

Subjects

The subjects were drawn from CFB Portage La Prairie base personnel and consisted of 335 males and 34 females, ranging in age from 18 to 49 years (Appendix 1). Anthropometric measures were taken on all subjects. Strength tests were administered to two groups (dynamic and static tests) drawn randomly from the sample population.

Anthropometric Measures

Thirty anthropometric measures were taken from each person. A complete list and description of these measures appears in Appendix 4. Not all persons who were anthropometrically measured performed the strength tests.

Strength Measures

Dynamic and static tests were administered to two groups of subjects selected from the sample population. The following five dynamic strength tests were administered to 142 males and 6 females:

1. Maximum number of sit ups in one minute
2. Maximum number of push ups in one minute
3. Right hand grip strength
4. Left hand grip strength
5. Maximum vertical jump

The following 4 static strength tests were administered to 56 males and 9 females:

1. Leg strength
2. Arm strength
3. Back strength
4. 15 inch pull

A complete description of the dynamic and static strength tests used in this study appear in Appendix 5. The small number of females participating in the study did not make statistical examination of their strength or anthropometric data feasible.

[Note: Grip strength is included as a dynamic measure. This was done for test administration purposes only.]

RESULTS

All experimental variables were intercorrelated by means of the Pearson product method. Based upon a level of significance of 0.05, the static strength tests required a correlation coefficient of 0.26 (n $\doteq$ 56) in order to be considered significant. Similarly, a correlation coefficient of 0.17 (n=142) was required for significance for the dynamic strength tests.

The intercorrelations between the anthropometric variables appear in Tables 1 to 6. Table 7 features the intercorrelations between the static tests and dynamic tests. Tables 8 and 9 present correlation data between the anthropometric and strength variables. Because of the large number of variables, all tables feature only the highest correlations.

Anthropometric ratios and lean body mass were calculated and correlated to static strength measures (Appendix 9). Multiple linear regression indicated that a larger percentage of the predicted variance for the static and dynamic tests was accounted for by the combination of several anthropometric variables. The regression equations for each strength test appears in Appendices 7 and 8.

Anthropometry (335 males):

The simple correlation coefficients between the anthropometric measures appear in Tables 1 to 6. In general, the correlations of linear measures to one another and the correlation of girth measurements to one another were greater than the correlations of linear with girth measures (Tables 1,2,3).

Table 1. Anthropometric Intercorrelations (linear variables).

MEASUREMENTS	COEFFICIENTS
Height - Overhead reach	.89
Functional reach - Upper arm length	.81
Buttock-Heel length - Height	.77
Height - Seated height	.70
Functional reach - Buttock-Heel length	.68
Buttock-Heel length - Buttock-Popliteal length	.66

Table 2. Anthropometric Intercorrelations (girth variables).

MEASUREMEMTS	COEFFICIENTS
Cir at Omphalion - Chest cir	.88
Cir at Omphalion - Buttock cir	.85
Flexed forearm cir - Flexed biceps cir	.76
Relaxed biceps cir - Chest cir	.75
Thigh cir - Flexed biceps cir	.72
Calf cir - Flexed forearm cir	.67

Table 3. Anthropometric Intercorrelations (girth vs linear).

MEASUREMENTS	COEFFICIENTS
Chest cir - Height	.87
Buttock cir - Buttock-Popliteal length	.49
Buttock cir - Overhead reach	.39
Thigh cir - Buttock-Popliteal length	.34
Calf cir - Buttock-Heel length	.30
Relaxed biceps cir - Upper arm length	.22

In general, relatively high intercorrelations were found between skinfold measures (Table 4). As might be expected, the skinfold measures were more highly correlated with girth measures than with linear measures (Tables 5 and 6). The highest correlation between skinfold measures and linear measures was $r=0.26$, between subscapular skinfold and buttock-popliteal length (Table 5). The highest correlation between the skinfold measures and girth measures was $r=0.72$ between subscapular skinfold and circumference at omphalion (Table 6).

Table 4. Anthropometric Intercorrelations (skinfold variables).

MEASUREMENTS	COEFFICIENTS
Subscapular - Suprailiac	.73
Subscapular - Biceps	.65
Triceps - Biceps	.63
Biceps - Suprailiac	.63

Table 5. Anthropometric Intercorrelations (skinfold vs linear).

MEASUREMENTS	COEFFICIENTS
Subcsapular skinfold - Buttock-Popliteal length	.26
Calf skinfold - Buttock-Popliteal length	.21
Suprailiac skinfold - Buttock-Heel length	.17
Biceps skinfold - Upper arm length	.10
Triceps skinfold - Upper arm length	.10

Table 6. Anthropometric Intercorrelations (skinfold vs girth).

MEASUREMENTS	COEFFICIENTS
Subscapular skinfold - Cir at Omphalion	.72
Suprailiac skinfold - Buttock cir	.61
Biceps skinfold - Chest cir	.51
Triceps skinfold - Thigh cir	.43
Calf skinfold - calf cir	.33

Strength Intercorrelations:

Static and dynamic strength tests were conducted on 56 and 142 males, respectively. Of the six intercorrelations between the static strength tests, four reached significance at the the 0.05 level (Table 7). The highest correlation coefficient was 0.63 between the 15 inch pull test and back strength. Of the ten intercorrelations between the dynamic strength tests, four reached significance at the 0.05 level. The highest correlation found was $r=0.78$, between right and left hand grip strength. Vertical jump was significantly correlated to all other dynamic measures.

Table 7. Strength Intercorrelations.

MEASUREMENTS	COEFFICIENTS
STATIC (n = 56)	
15 inch pull - Back strength	.63
Arm strength - Leg strength	.40
Back strength - Arm strength	.39
15 inch pull - Arm strength	.28
DYNAMIC (n = 142)	
Right grip - Left grip	.78
Sit ups - Push ups	.56
Sit ups - Vertical jump	.42
Push ups - Vertical jump	.38

Strength-Anthropometry Correlations:

The simple correlation coefficients between the various measures of strength and anthropometry are contained in Tables 8 and 9. In general, the correlations were low, with slightly higher correlations being found between anthropometry and static strength tests than with dynamic strength tests.

The anthropometric measures most highly correlated with static strength were chest circumference, calf circumference, bideltoid breadth, thigh circumference, and buttock circumference, where the highest correlation coefficient was 0.46 between chest circumference and back strength. Leg strength was the static measure most poorly correlated with anthropometry, the best correlation being r=0.33 with calf skinfold .

Correlations of dynamic tests with other measures of anthropometry were generally low. Age was more highly correlated than girth or linear measures, with the highest coefficients being -0.50 with sit-ups, and -0.42 with vertical jump. Right hand grip strength correlated best with hand breadth, flexed forearm circumference and hand length with coefficients of 0.41, 0.35 and 0.32, respectively.

Table 8. Strength-Anthropometry Correlations (Static tests).

MEASUREMENTS	COEFFICIENTS
Back strength - Chest cir	.46
Back strength - Calf cir	.46
Back strength - Bideltoid breadth	.44
15 inch pull - Thigh cir	.41
15 inch pull - Calf cir	.41
15 inch pull - Buttock cir	.41
Back strength - Weight	.40
Arm strength - Calf cir	.39
Arm strength - Flexed forearm cir	.38
15 inch pull - Weight	.37
Leg strength - Calf skinfold	.33
Leg strength - Biacromial breadth	.19
Arm strength - Seated height	.29
Arm strength - Hand length	.23
Leg strength - Functional reach	.16
15 inch pull - Buttock-Popliteal length	.10
Back strength - Upper arm length	.10

Table 9. Strength-Anthropometry Correlations (Dynamic tests).

MEASUREMENTS	COEFFICIENTS
Sit ups - Age	-.50
Vertical jump - Age	-.42
Right hand grip strength - Hand breadth	.41
Right hand grip strength - Flexed forearm cir	.35
Right hand grip strength - Hand length	.32
Sit ups - Cir at Omphalion	-.34
Push ups - Cir at Omphalion	-.33
Push ups - Age	-.32
Push ups - Buttock-Heel length	-.31
Push ups - Suprailiac skinfold	-.30
Sit ups - Subscapular skinfold	-.26
Sit ups - Standing hip breadth	-.22
Vertical jump - Biceps skinfold	-.22
Vertical jump - Cir at omphalion	-.22

Multiple linear regression analysis (stepwise-up) indicated that strength was related to a combination of selected anthropometric variables. A range of 22 - 46 percent of the predicted variance in the dynamic and static tests was accounted for by the selection of seven different anthropometric variables for each strength test (Appendices 7 and 8).

In general, derived anthropometric ratios correlated poorly with the static strength measures (Appendix 9). The highest correlation was r= -0.42 between chest circumference/body weight with arm strength, reciprocal ponderal index (RPI) with back strength and r=0.42 for calf circumference/buttock-heel length with back strength. Ponderal index (PI = weight/cube root height) was significantly correlated with arm strength (r=0.35), back strength (r=0.41), and 15 inch pull (r=0.38), but not with leg strength (r=0.03). Overall, the derived ratios yielded lower correlations with strength than did direct anthropometric measures. A list of the ratios calculated in this study appears in Appendix 9.

DISCUSSION

The results of the intercorrelations between the anthropometric measures were, for the most part, comparable to those found in previous studies (1,5,12,13). For example, Roberts et al. (1) reported a correlation coefficient of 0.47 between height and weight, whereas a coefficient of 0.48 was found in the present study. Comparison of various anthropometric intercorrelations from this and other studies appear in Table 10.

Table 10. Comparison of Anthropometric Intercorrelations.

MEASUREMENTS	LITERATURE (Ref.)	PRESENT STUDY
Thigh cir - Calf cir	0.72 (5)	0.67
Thigh cir - Weight	0.87 (5)	0.73
Flexed biceps cir - Forearm cir	0.70 (1)	0.76
Flexed biceps cir - Weight	0.72 (12)	0.79
Calf girth - Weigth	0.74 (5)	0.76
Height - Leg length	0.77 (5)	0.77
Height - Upper arm length	0.54 (13)	0.55
Height - Seated height	0.70 (5)	0.70
Hand length - Height	0.75 (1)	0.63
Hand length - Upper arm length	0.51 (1)	0.39
Thigh cir - Height	0.19 (1)	0.24
Calf cir - Height	0.14 (1)	0.30
Thigh cir - Leg length	0.13 (1)	0.23
Upper arm length - Upper arm cir	0.30 (5)	0.22
Forearm cir - Upper arm length	0.14 (5)	0.30

Roberts et al. (1), reported a fairly close relationship between the various girth measures as well as a close relationship between the different linear measures. It was pointed out, however, that these measures were poorly related to each other (similar results were found in the present study). It was suggested that this relationship was due to some fundamental difference between longitudinal and circumferential measurements (1). Another possible explanation is that variations in body weight, reflected as changes in body circumference, resulted in the low correlations between length and circumference measures.

Comparisons of the correlations between anthropometry and strength measures with previous studies were somewhat inconsistent. Clarke (5) reported a correlation of r=0.58 between back strength and weight. In the present study, a correlation of r=0.40 was found between these two parameters. Also in the present study, a correlation of r=0.38 was obtained between flexed forearm circumference and arm strength. Roberts et al. (1), in a study of 75 Royal Navy personnel, found a correlation of r=0.64 between these same measures. In that same study (1), arm strength yielded coefficients of 0.47, 0.34 and 0.40 with weight, upper arm length and flexed biceps circumference, respectively. In the present study, coefficients of 0.36, 0.10 and 0.18 were obtained between these same parameters and arm strength.

Leg strength was the static strength measure most poorly correlated with measures of anthropometry (the highest correlation being r=0.33 for calf skinfold). The remaining correlations between leg strength and other anthropometric variables were generally low, with measures such as height and calf circumference yielding coefficients of 0.07 and 0.11, respectively. Other investigators reported similar low correlations between leg strength and various anthropometric measurements. Laubach and McConville (6) found correlations of r=0.19 and r= -0.10 for leg extension strength with weight and thigh length, respectively. These same paramaters yielded correlation coefficients of 0.04 and -0.05 in the present study. Much higher correlations were reported by Clarke (5), for weight, height and thigh circumference with leg strength, yielding coefficients of 0.64, 0.84 and 0.52, respectively.

In the present study, the 15 inch pull test was most closely related to thigh circumference with a correlation of r=0.41. Moderate levels of correlation were also obtained with weight, buttock circumference and calf circumference with coefficients of 0.37, 0.41 and 0.41, respectively. No other studies which correlated the 15 inch pull test to anthropometric variables were available for comparison.

No studies were found that independently related sit ups, push ups, and vertical jump to anthropometry. Clarke (13) examined the relationship between anthropometric measures and various composite strength scores derived from pull ups, push ups and weight. He found correlations coefficients ranging from -0.04 to 0.74 between composite strength scores and measures of height, upper arm length and upper arm girth. Much lower correlations were found, however, when such composite indices were not formed, as was the case in the present study. The highest correlation obtained was r= -0.34 between push ups and circumference at omphalion. The results of this study indicate that dynamic measures such as push ups, sit ups and vertical jump, when examined independently, are poorly related to anthropometry.

Some investigators have reported high correlations between anthropometry and strength when regression analysis is used. Roberts et al. (1) reported a correlation coefficient of 0.72

between upper arm girth, stature, weight and elbow extension strength. Lamphiear and Montoye (4) examined the relationships of arm strength and grip strength to a combination of anthropometric measures. In the preliminary regression, five size variables were selected yielding correlation coefficients of 0.55 with grip strength and 0.55 with arm strength. When the same five variables were examined in relation to hand grip and arm strength in the present study, coefficients of 0.40 for hand grip strength and 0.44 for arm strength were found.

It should be emphasized that regression analysis is limited in its ability to predict strength. As the number of variables entering the regression are increased, the equation formed becomes more specific to that particular sample. These derived equations should only be applied to other populations when the characteristics of the sample population are representative of the intended population. This transformation, however, leads to some loss of accuracy in prediction.

SUMMARY

In summary, the results indicate that the measures of anthropometry examined here are only moderately related to the measures of strength used in this study.

Upon close examination of the literature pertaining to anthropometry and strength, many inconsistencies in methodology become apparent. Such inconsistencies may, in part, account for the large variations in reported results. A number of items to consider are listed below:

1. The force exerted and the degree of involvement of different muscle groups depends, in part, on the posture employed. In numerous studies, different postures were used, such as sitting as opposed to standing, or prone as opposed to sitting. As well, the choice of unilateral or bilateral testing apparatus will affect the results.

2. In order to make valid comparisons between various studies, standardization of measurement technique must be assured. In the present study, for example, leg length was defined as the distance between heel surface (in dorsiflexion) and the posterior gluteal surface measured from a sitting position. Clarke (5), however, defined this measure as the difference between sitting and standing height.

3. Motivation and the type of instruction given to the subject during and after any physical manoeuvre will affect performance. In some cases the experimenter provides encouragement to the subject during the test, urging him to exert his maximum effort. Performance in this case will differ from the situation in which encouragement is not provided. The

data may also be affected if the experimenter provides the subject with results after each performance. Knowledge of results is viewed to be a form of indirect motivation (19).

Many researchers have found significant relationships between various anthropometric measures and strength. However, a significant relationship does not necessarily imply the existence of practical predictive power. The low correlations found in this and other studies, suggest that factors other than those being measured and observed are contributing to the generation of strength. In order to more fully understand and predict muscular strength, these factors must be identified and accounted for.

RECOMMENDATIONS

The development of occupational physical selection standards (OPSS) is currently being studied in order to accurately assess the physical requirements necessary to perform in physically demanding trades in the CF. This study examined the relationships between selected anthropometric measures and strength capabilities (static and dynamic) as a possible component of the selection procedure. The results of this study show that these measures are poorly related (in many cases $r<0.50$). This does not necessarily mean that all relationships between anthropometry and strength are useless. As was discussed in the review section of this paper, the literature has demonstrated high correlations between many parameters, some of which have not been addressed in the present study. If improved relationships can be found, then anthropometry could substitute for the more involved measures of strength.

The low correlations found in the present study may have been due to the general nature of the anthropometric and strength measures involved. The proposed methodology for the OPSS study will attempt to utilize anthropometric and strength variables that have been specifically chosen to define the biomechanical actions and body postures representative of the trade demands. It is expected, then, that with increased specificity higher correlations and useful predictive capability will be realized.

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APPENDIX 1

Height and Weight Data of the Subject Pool.

The following table compares the height and weight data of the present subject population with previous CF population surveys:

		Present Study		CF Population	
		Male	Female	Male (1975)	Female (1978)
Height	(Mean)	176.0 cm	163.2 cm	175.0 cm	162.7 cm
	(S.D.)	6.7 cm	6.7 cm	6.3 cm	6.1 cm
Weight	(Mean)	78.2 kg	62.3 kg	76.9 kg	61.7 kg
	(S.D.)	11.1 kg	7.1 kg	11.7 kg	8.1 kg
n		335	34	565	137

(CF male and female data from 15 and 16, respectively)
(S.D. - Standard Deviation)

APPENDIX 2

Means and Standard Deviations of Anthropometric Measurements (males).

MEASUREMENTS	MEAN	S.D.	n
Weight	78.2 kg	11.1	335
Height	176.0 cm	6.7	335
Biacromial breadth	41.3 cm	1.7	335
Bideltoid breadth	48.3 cm	2.8	335
Standing hip breadth	34.5 cm	2.0	335
Cnest breadth	33.2 cm	2.4	335
Seated height	92.1 cm	3.5	335
Buttock-Popliteal length	49.1 cm	2.7	335
Humerus diameter	7.1 cm	0.4	335
Femur diameter	9.3 cm	0.6	335
Hand breadth	8.9 cm	0.4	335
Hand length	19.1 cm	0.9	335
Flexed forearm cir	30.3 cm	1.9	335
Flexed biceps cir	34.5 cm	2.8	335
Relaxed biceps cir	30.6 cm	2.5	335
Head circumference	57.7 cm	2.0	335
Chest circumference	100.6 cm	7.5	335
Cir at omphalion	91.6 cm	9.3	335
Buttock circumference	99.1 cm	6.0	335
Thigh circumference	53.2 cm	4.1	335
Calf circumference	37.2 cm	2.7	335
Overhead reach	228.2 cm	8.9	335
Functional reach	78.3 cm	4.0	335
Upper arm length	42.6 cm	2.8	335
Buttock-Heel length	110.7 cm	5.3	335
Biceps skinfold	5.6 mm	2.2	335
Triceps skinfold	10.9 mm	3.6	335
Subscapular skinfold	16.2 mm	6.4	335
Suprailiac skinfold	20.1 mm	8.8	335
Calf skinfold	9.4 mm	3.6	335

APPENDIX 3

Means and Standard Deviations of Anthropometric Measurements (females).

MEASUREMENTS	MEAN	S.D.	n
Weight	62.3 kg	7.1	34
Height	163.2 cm	6.7	34
Biacromial breadth	37.5 cm	1.5	34
Bideltoid breadth	43.2 cm	2.0	34
Standing hip breadth	34.4 cm	2.1	34
Chest breadth	29.2 cm	1.5	34
Seated height	86.9 cm	3.8	34
Buttock-Popliteal length	46.8 cm	2.3	34
Humerus diameter	6.2 cm	0.3	34
Femur diameter	8.7 cm	0.5	34
Hand breadth	7.8 cm	0.3	34
Hand length	17.5 cm	0.9	34
Flexed forearm cir	25.9 cm	1.6	34
Flexed biceps cir	29.6 cm	2.5	34
Relaxed biceps cir	27.9 cm	2.4	34
Head circumference	55.1 cm	1.2	34
Chest circumference	95.1 cm	6.5	34
Cir at omphalion	80.7 cm	6.3	34
Buttock circumference	98.5 cm	5.4	34
Thigh circumference	53.0 cm	4.0	34
Calf circumference	36.2 cm	2.7	34
Overhead reach	211.2 cm	8.7	34
Functional reach	71.0 cm	3.5	34
Upper arm length	38.3 cm	2.5	34
Buttock-Heel length	101.3 cm	5.4	34
Biceps skinfold	8.0 mm	4.2	34
Triceps skinfold	17.0 mm	4.4	34
Subscapular skinfold	14.1 mm	4.1	34
Suprailiac skinfold	15.5 mm	6.4	34
Calf skinfold	15.9 mm	4.4	34

APPENDIX 4

Anthropometric Definitions

[Note: All measurements were taken to the nearest 0.1 cm unless otherwise indicated.]

1. WEIGHT (MASS)

Subject stands erect on medical scales. Mass is recorded to the nearest 0.1 kilogram.

2. HEIGHT

Subject stands erect, line of sight horizontal and heels together. With the arm of the anthropometer touching the scalp in the midsaggital plane, the vertical distance from the standing surface to the top of the head is measured.

3. BIACROMIAL BREADTH

Subject stands erect, with heels together and arms relaxed at the sides. The horizontal distance between the two acromial landmarks is measured with beam calipers.

4. BIDELTOID BREADTH

Subject stands erect with heels together and arms relaxed at the sides. The horizontal distance between the two deltoid landmarks is measured with beam calipers.

5. STANDING HIP BREADTH

Subject stands erect with heels together and arms slightly abducted. The horizontal distance between the two trochanter landmarks is measured with beam calipers.

6. CHEST BREADTH

Subject stands erect, with heels together and arms sligthly abducted. The horizontal breadth at bustpoint height is measured at the average point of quiet respiration using beam calipers.

7. SEATED HEIGHT

Subject sits erect on the measuring bench, line of sight horizontal and feet supported so that the thighs are in the horizontal plane and parallel. With the arm of the anthropometer touching the scalp in the midsaggital plane, the vertical distance from the sitting surface to the top of the head is measured.

8. BUTTOCK-POPLITEAL LENGTH

Subject sits erect on the measuring bench, with feet supported so that the thighs are in a horizontal plane and parallel. The lower leg is vertical, with the popliteal in light contact with the front edge of the bench. A measuring block is held against the most posterior aspect of the right buttock and the horizontal distance from the front end of the table to the block is measured on the bench scale.

9. HUMERUS DIAMETER

Subject sits relaxed on measuring bench. With the elbow bent to 90 degrees, the right arm is raised so that the upper arm surface is parallel to the floor. The horizontal distance across the humeral condyles is palpated and measured using spreading calipers.

10. FEMUR DIAMETER

Subject sits relaxed on measuring bench with thighs parallel to the floor. With the right knee slightly extended, the horizontal distance across the femeral condyles is palpated and measured using spreading calipers.

11. HAND BREADTH

The subject's right hand is pronated and rests lightly on a table, fingers together and straight (but not hyperextended) and the thumb held apart. The breadth of the hand between the second and fifth metacarpal-phalangeal joints is measured, using the sliding calipers.

12. HAND LENGTH

The subjects right hand is supinated and rests lightly on a table, with fingers together and straight (but not hyperextended). With the bar of the sliding calipers held parallel to the long axis of the hand, the distance from the dactylion (tip) to the distal wrist crease is measured.

13. FLEXED FOREARM CIRCUMFERENCE

Subject stands erect, right arm extended horizontally forward, elbow flexed and forearm raised vertically. The fist is tightly clenched and the forearm muscles maximally contracted. With the measuring tape held in a plane perpendicular to the long axis of the right forearm, the maximum forearm circumference is measured.

14. FLEXED BICEPS CIRCUMFERENCE

Subject stands erect, right arm extended horizontally forward, elbow flexed and forearm raised vertically. The fist is tightly clenched and the biceps maximally contracted. With the measuring tape held in a plane perpendicular to the long axis of the right upper arm, the maximum biceps circumference (biceps landmark) is measured.

15. RELAXED BICEPS CIRCUMFERENCE

Subject stands erect, right arm extended horizontally forward and biceps relaxed. With the measuring tape held in a plane perpendicular to the long axis of the right arm, the circumference at the biceps landmark is measured.

16. HEAD CIRCUMFERENCE

Subject stands erect, with line of sight horizontal. The horizontal circumference of the head is measured, with the measuring tape held just above the glabella landmark.

17. CHEST CIRCUMFERENCE

Subject stands erect, with arms slightly abducted. The measuring tape is held in a horizontal plane and the circumference of the chest at bustpoint height is measured, at the average point of quiet respiration.

18. CIRCUMFERENCE AT OMPHALION

Subject stands erect, with heels together and is asked to relax abdominal muscles. The measuring tape is held in a horizontal plane at the level of the omphalion and the circumference is measured at the average point of quiet respiration.

19. BUTTOCK CIRCUMFERENCE

Subject stands erect with heels together. The measuring tape is held in a horizontal plane at the level of the greatest gluteal protuberence and at about the level of the symphysion (superior border of the pubis symphysion).

20. THIGH CIRCUMFERENCE

Subject stands erect with feet apart to shoulder width. The measuring tape is positioned at the vertical midpoint level of the thigh and the circumference is measured.

21. CALF CIRCUMFERENCE

Subject stands erect, with feet about 10 cm. apart. The maximum horizontal circumference of the right calf is measured with the measuring tape.

22. OVERHEAD REACH

Subject stands erect, with heels together and buttocks and shoulders against the wall. The right arm is extended vertically upward, while the heels remain in contact with the standing surface. With the right arm fully extended, the tips of the phalanges are used to push a measuring block up the wall to a maximum vertical height. The vertical distance from the standing surface to the block is measured from a fixed wall scale (chart).

23. FUNCTIONAL REACH

Subject stands erect, with back against one wall of the corner and right arm extended horizontally forward along the other wall. The right hand is pronated and fingers clenched to form a fist. The thumb is then fully extended below the fist, in horizontal line with the forearm. The heels, buttocks and shoulders are held firmly against the wall and a measuring block is held against the tip of the extended thumb. The horizontal distance from the back of the wall to the block is measured on a wall scale.

24. UPPER ARM LENGTH

Subject stands erect in the corner, with back against one wall and right scapula touching the wall. The right arm is extended horizontally forward and the elbow flexed so that the forearm projects horizontally and perpendicular to the side wall. A measuring block is held against the distal edge of the upper arm at the olecranon process, and the horizontal distance from the wall to the block is measured on the wall scale.

25. BUTTOCK HEEL LENGTH

Subject sits on the floor, with back against the wall, right leg extended forward along the floor scale and left leg flexed. Leaning forward and forcing buttocks tightly against the wall, the right knee is fully extended and the right ankle maximally dorsiflexed. A measuring block is placed against the plantar surface of the right foot and the distance from the wall to the block is measured on the floor scale.

26. BICEPS SKINFOLD

Subject stands relaxed and erect with arms by the sides. The skinfold is raised using the thumb and forefinger on the front right upper arm over the biceps muscle at the mid-arm point. The skinfold is lifted parallel to the long axis of the arm and the measurement is taken using skin calipers (nearest 0.1 mm).

27. TRICEPS SKINFOLD

The subject stands relaxed and erect with the arm by the side and elbow extended. The skinfold is raised using the thumb and forefinger over the triceps muscle on the back of the right arm at the mid-arm point. The skinfold is lifted parallel to the long axis of the arm and the measurement is taken using skinfold calipers (nearest 0.1 mm).

28. SUBSCAPULAR SKINFOLD

Subject stands relaxed and erect with the arm by the side and elbow extended. The skinfold is raised using the thumb and forefinger below the inferior angle of the right scapula and running downward and outward in the direction of the ribs. The measurement is taken using skinfold calipers (nearest 0.1 mm).

29. SUPRAILIAC SKINFOLD

Subject stands relaxed and erect with the right arm abducted slightly. The skinfold is raised using the thumb and forefinger at a position one or two inches above the crest of the ilium at the mid-line of the body, so that the skinfold runs forward and slightly downward. The skinfold is raised a few times to determine the natural fold. The measurement is taken using skinfold calipers (nearest 0.1 mm).

30. CALF SKINFOLD

The subject stands resting the right knee on the measuring bench such that the lower leg is parallel to the bench surface and relaxed. The skinfold is raised using the thumb and forefiger on the inside of the right calf just below the level of maximum calf girth so that the fold runs along the long axis of the lower leg. The measurement is taken using skinfold calipers (nearest 0.1 mm).

[Note: Skinfold data represents the average value over 2 trials.]

APPENDIX 5

Definition of Strength Measures

DYNAMIC MEASURES

1. Sit ups: Sit ups were performed from a flexed knee position with the feet held flat on the floor. Hands were placed behind the head. From the lying position, the subject sat up and touched both elbows to his knees. A complete cycle was from supine position to supine position. The test lasted 60 seconds for the males and 30 seconds for the females.

2. Push ups: Push ups were performed from a front-lying position with the hands at the side of the chest. The body was raised by extending the arms completely while keeping the body in a staight line. Females performed a modified push ups (knees on floor, leg bent). A complete cycle was from prone positon to prone position. The test lasted 60 seconds for the males and 30 seconds for the females.

3. Vertical jump: The subject stood flat footed facing a wall and reached as high as possible over his head and marked this height with chalk. The subject then moved to a comfortable position away from the wall with either side to the wall and prepared to jump. With the chalk held in the hand closest to the wall, the subject jumped as high as possible and marked the wall at maximum height with chalk. Two practice jumps and three trials were allowed. The distance between the standing height mark and the maximum jump height was recorded to the nearest centimeter.

4. Hand grip strength: The dynamometer was adjusted so that the thumb touched or overlapped the first finger. The pointer was set to zero and the subject squeezed the dynamometer as hard as possible, keeping the hand away from the side of the body. The score was recorded to the nearest kilogram. The other hand was tested similarly. Trials were repeated for each hand and the highest value recorded.

STATIC MEASURES

1. 15 inch pull: Apparatus consisted of force monitor platform and long handle adjusted to 38 cm above the platform. Subjects stand with feet 45 cm apart and knees bent. Bending at the waist and grasping both sides of the long handle, the subjects attempt to pull the handle using the arms and shoulders. In doing this the subject also uses his legs by extending them upward while pulling.

2. Leg strength: The position of the subject for leg strength is shown in Figure 1 (14). The subject was asked to sit as far back as possible in the chair with the arch of his foot on the leg force bar. The seat belt was placed tightly around his waist. The position of the leg force bar was adjusted so that a 90 degree angle was obtained at the knee. The subject was told to pull himself down onto the seat at the same time he pushed on to the force bar. He was additionally told not to flex his trunk.

3. Arm (upper body) strength: The position of the subject for measurement of upper body strength was similar to that used for leg strength (Figure 2)(14). The subject grasped the force bar such that his hands were about shoulder distance apart and equidistant from the centre of the bar. The upper arm was parallel to the floor and the elbow was at 90 degrees. The subject was told to pull down as hard as possible on the bar without flexing his trunk.

4. Back (trunk) Strength: The standardized position for trunk extension measurement is shown in Figure 3 (14). The seat was removed and the abdominal plate placed against the main supporting beam. The subject stood facing the apparatus with his feet against the toe piece and as close together as possible. The breast plate and nylon strap were placed around the arms and back with the top of the strap, three inches inferior to the acromion process. Subjects were instructed to pull back as hard as possible on the strap while pushing forward with their hips on the abdominal pad. Hands were kept on the thighs, and the subject instructed not to bend his knees.

[Note: The subjects were instructed to build to maximal strength as rapidly as possible without jerking and maintain that level of exertion for about three to five seconds. Figures appear courtesy of US Army Research Institute of Environmental Medicine (14)].

Figure 1. Subject Positioning for Leg Strength Measurement.

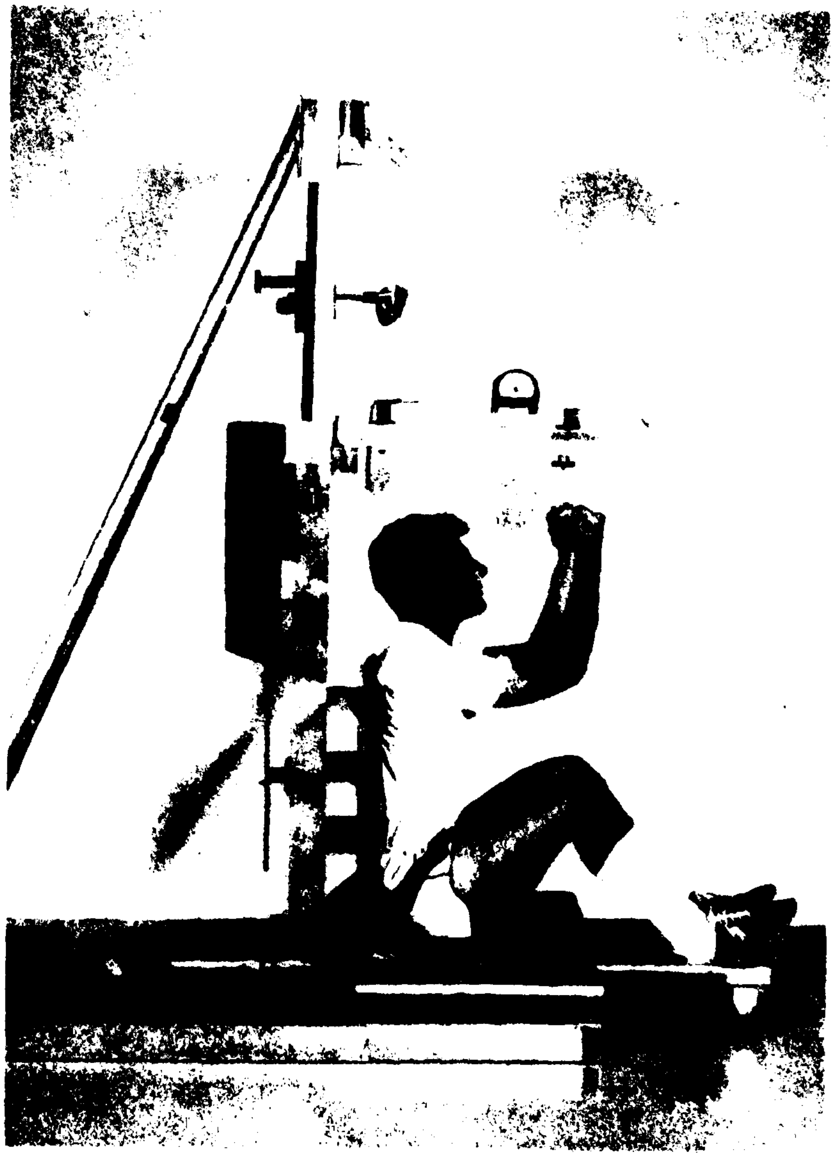

Figure 2. Subject Positioning for Upper Body Strength Measurement.

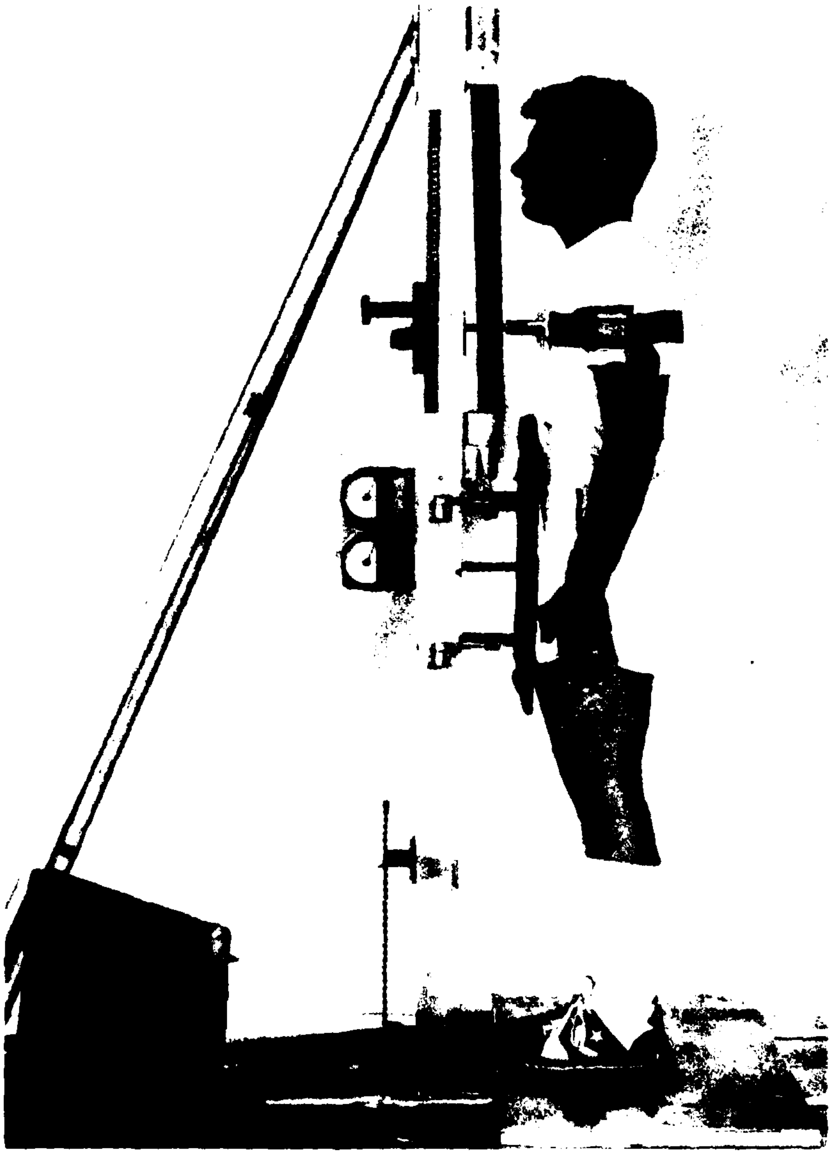

Figure 3. Subject Positioning for Trunk Strengt' Measurement.

APPENDIX 6

Means and Standard Deviations of Strength Measurements (males).

MEASUREMENT	MEAN (S.D.) PRESENT STUDY	MEAN (S.D.) US ARMY DATA
Static Tests		
Leg strength	196.7 (47.5) kg	142.5 (37.8) kg
n	56	947
Arm strength	102.7 (17.2) kg	97.2 (18.7) kg
n	56	924
Back strength	88.4 (17.9) kg	72.3 (18.7) kg
n	56	934
15 inch pull	144.0 (50.9) kg	138.0 (24.0) kg
n	56	221
Dynamic Tests (n = 142)		
Sit ups	31.9 (8.4) (1 min)	
Push ups	22.7 (10.8) (1 min)	
Right hand grip	53.0 (8.3) kg	
Left hand grip	50.5 (7.6) kg	
Vertical jump	43.1 (8.4) cm	

[Note: US Army data for leg, arm and back strength from Reference 14. US Army 15" pull data from Reference 18.]

APPENDIX 7

Regression Equations for Static Measures.

Condition	R	Regression Equations
Leg strength	.61	-14.56 (Ca sf) -14.81 (F.B. cir) + 23.75 (F.F. cir) + 13.65 (Bu cir) - 20.20 (St hip br) - 9.48 (U.A. lth) - 3.09 (Cir O) + 320.04
Arm strength	.67	- 3.02 (Cir O) + 3.00 (Wt) - 5.61 (B-P lth) + 3.04 (B-H lth) + 11.27 (F.F. cir) - 4.77 (F.B. cir) - 2.18 (Fu rch) + 203.25
Back strength	.65	5.21 (Ch cir) - 1.14 (Sup sf) + 3.31 (Bu cir) - 1.18 (age) - 1.66 (Ht) - 2.73 (Cir O) + 1.98 (Ca sf) - 72.74
15 inch pull	.68	- 3.50 (age) + 3.90 (Bu cir) + 5.12 (Ch cir) - 2.18 (Ov rch) - 3.26 (Cir O) + 31.92 (Hu dia) + 2.39 (Ca sf) + 73.29

Age:	Age	F.F. cir:	Flexed forearm cir
B-H lth:	Buttock-Heel lth:	Fu rch:	Functional reach
B-P lth:	Buttock-Popliteal lth	Ht:	Height
Bu cir:	Buttock cir	Hu dia:	Humerus diameter
Ca sf:	Calf skinfold	St hip br:	Standing hip breadth
Ch cir:	Chest cir	Sup sf:	Suprailiac skinfold
Cir O:	Cir at Omphalion	U.A. lth:	Upper arm length
F.B. cir:	Flexed biceps cir	Wt:	Weight

APPENDIX 8

Regression Equations for Dynamic Measures.

Condition	R	Regression Equations
Sit ups	.65	-0.50 (age) - 0.29 (Cir O) + 1.27 (Sup sf) - 0.32 (Sub sf) + 0.47 (B-P lth) - 1.47 (Fe dia) - 0.52 (St hip br) + 46.94
Push ups	.59	- 0.33 (Cir O) + 1.12 (F.B cir) - 0.48 (age) -0.62 (Ca cir) - 0.31 (Ht) - 0.23 (Sup sf) + 0.36 (Th cir) + 78.89
Right hand grip strength	.56	0.51 (Th cir) - 0.83 (Bi sf) + 0.78 (F.F. cir) + 4.05 (Hand br) + 0.50 (B-P lth) - 0.22 (Sub sf) + 0.40 (Ch br) - 63.48
Left Hand grip strength	.48	0.94 (F.F cir) - 0.42 (Cir O) + 0.68 (Bidel br) + 0.53 (B-P lth) + 0.25 (Ch cir) + 1.67 (Hand br) - 0.11 (Sub sf) - 37 .36
Vertical jump	.63	-0.50 (age) - 0.53 (Ca sf) + 1.12 (F.B. cir) - 0.27 (Cir O) + 0.76 (Biac br) - 0.61 (Bi sf) + 0.34 (B-P lth) + 8.44

Age:	Age	Cir O:	Cir at Omphalion
Biac br:	Biacromial breadth	F.B. cir	Flexed Biceps cir
Bidel br:	Bideltoid breadth	Fe dia:	Femur diameter
Bi sf:	Biceps skinfold	F.F. cir	Flexed forearm cir
B-P lth:	Buttock-Popliteal lth	Ht:	Height
Ca cir:	Calf cir	Sub sf:	Subscapular skinfold
Ca sf:	Calf skinfold	Sup sf:	Suprascapular skinfold
Ch br:	Chest breadth	St hip br:	Standing hip breadth

APPENDIX 9

Anthropometric Ratios vs. Static Strength Measures.

MEASUREMENTS	LEG	ARM	BACK	15" PULL
	Correlation Coefficients			
Wt/cube root Ht (PI)	0.03	0.35	0.41	0.38
Ch cir/Wt	-0.08	-0.42	-0.25	-0.32
Biac dia/Ch cir	0.08	-0.06	-0.31	-0.26
Bidel dia/Ch cir	0.04	0.07	-0.15	-0.13
Th cir/Ch cir	-0.01	0.08	-0.13	0.02
Sea Ht/St Ht	-0.07	0.11	0.09	0.07
F.F. cir/Th cir	0.20	0.18	0.02	-0.12
F.B. cir/Th cir	0.12	0.01	0.20	0.11
R.B. cir/Th cir	-0.18	-0.08	-0.01	-0.14
Ch cir X Ht	0.04	0.29	0.40	0.33
Th cir/Biac dia	-0.09	0.12	0.21	0.26
St hip br/Ch cir	-0.06	-0.03	-0.25	-0.26
Biac dia/St hip br	0.16	-0.05	-0.13	-0.06
Bidel br/St hip br	0.10	0.08	0.13	0.16
B-H lth/Ht	-0.17	0.08	-0.02	-0.07
Sea Ht/B-H lth	0.15	0.01	0.04	0.09
Ca cir/B-H lth	0.14	0.23	0.42	0.40
Th cir/B-H lth	0.05	0.11	0.36	0.39
St hip br/Ht	-0.09	0.11	0.40	0.27
Wt/Ht squared	-0.19	-0.10	0.22	0.16
Ht/cube root Wt (RPI)	-0.01	-0.18	-0.42	0.16
F.B. cir/Ca cir	-0.01	-0.15	0.06	0.03
R.B. cir/Ca cir	-0.17	0.03	0.24	0.15
F.F. cir/Ca cir	-0.01	-0.06	-0.17	-0.21
% body Fat	-0.26	0.00	0.10	0.11

B-H lth:	Buttock-Heel lth	Ht:	Height
Biac br:	Biacromial breadth	R.B. cir:	Relaxed Biceps cir
Bidel br:	Bideltoid breadth	Sea Ht:	Seated Height
Ca cir:	Calf cir	St Ht:	Standing hip breadth
Ch cir:	Chest cir	Th cir:	Thigh cir
F.B. cir:	Flexed Biceps cir	Wt:	Weight
F.F. cir:	Flexed Forearm cir	RPI:	Reciprocal Ponderal Index
		PI:	Ponderal Index