Assessment of Muscle Strength and Prediction of Lifting Capacity in U. S. Army Personnel

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and female soldiers. Initial analysis selected six isometric strength measures plus lean body mass as potential predictors of the best criterion variable, maximum lift capacity to 132 cm (MSLC). Males and females formed separate populations (non-coincidence) in these measures so that gender could be represented by a numerical designator as a constituent variable in a single predictive equation. Handgrip, 38 cm upright pull and upper torso pull down gave similar predictive power. Ridge regression techniques were utilized to compensate for multicollinearity effects among these predictors. This analysis and operational considerations reduced the final variables to the 38cm upright pull, lean body mass and gender. For lift capacity to 132cm, the equation derived was MSLC = -.8.466 + 0.9933 (LBM) + .006349(UP 38) - 4.777 (SEX) with males = 1 and females = 2 for SEX, resulting in a multiple correlation coefficient of 0.89. Median performances for males and females for MSLC was 57.1kg and 31.1kg, respectively. Males could lift 1.8 times more than females, but their isometric strength was only 1.5 - 1.6 times that of females.

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ABSTRACT

The purpose of this study was to determine muscular strength tests which would be appropriate for Army occupational selection and predictive of job lifting and lifting-carrying tasks. A maximum lift to 132 cm, dead lift to knuckle height and a short term self-paced maximal lift-and-carry were utilized as criterion tasks. Isometric strength measures evaluated as predictors included: handgrip, knee extension, trunk extension, upper torso arm-shoulder pull down, standing upward pull at 38 cm and 132 cm height. Dynamic strength of the trunk extensors were also measured with an isokinetic dynamometer. Studies employed both male and female soldiers. Initial analysis selected six isometric strength measures plus lean body mass as potential predictors of the best criterion variable, maximum lift capacity to 132 cm (MSLC). Males and females formed separate populations (non-coincidence) in these measures so that gender could be represented by a numerical designator as a constituent variable in a single predictive equation. Handgrip, 38cm upright pull and upper torso pull down gave similar predictive power. Ridge regression techniques were utilized to compensate for multicollinearity effects among these predictors. This analysis and operational considerations reduced the final variables to the 38cm upright pull, lean body mass and gender. For lift capacity to 132cm, the equation derived was MSLC = -8.466 + 0.9933 (LBM) + .006349(UP38) - 4.777(SEX) with males = 1 and females = 2 for SEX, resulting in a multiple correlation coefficient of 0.89. Median performances for males and females for MSLC was 57.1kg and 31.1kg, respectively. Males could lift 1.8 times more than females, but their isometric strength was only 1.5 - 1.6 times that of females.

1. Introduction

The implementation in the United States of an all volunteer Army, the increase in the total number of women joining and requesting non-traditional physically demanding trades, as well as the coincidental decline in total available manpower, has necessitated that a system be devised for matching the physical demands of army occupations to the capabilities of entering personnel. An extensive research effort has ensued to document occupational requirements and fitness capacity levels of recruits and to devise entrance screening tests that are suitable for predicting subsequent occupational performance. This report documents studies carried out to develop predictors of physical capacity that would be simple and safe to administer and yet sufficiently predictive so as to be suitable for job classification.

Early job physical task analysis of all 350 enlisted occupations in the US Army (Vogel,et al 1980) led to a clustering of occupations into two categories of work capacity (aerobic capacity and lifting capacity) at three levels of intensity. For lifting capacity, the three levels of intensity were derived from the most demanding tasks identified and were represented by the weights necessary to be lifted from the floor to chest height. This report is limited to the results of studies carried out to identify simple predictors of lifting capacity. Similar to maximal aerobic power being commonly used as the criterion variable for aerobic performance, we chose a single maximal impulse lift of a weighted box from ground to 132 cm (bed height of US military wheeled tactical vehicles) as the criterion variable for lifting performance. This measure was chosen after a survey of all occupational physical

tasks demonstrated that in excess of 90% of limiting tasks were infrequent single lifts or lift-and-carry tasks.

Predictive tests of aerobic power have been extensively researched in a variety of populations including other military forces (Nordesjo and Schele 1974). Manual materials handling and lifting capabilities have likewise been investigated albeit more in industrial and student populations (Snook and Irvine 1969, Poulsen 1970, Jorgensen and Poulsen 1974, Snook and Ciriello 1974, Chaffin et al 1978, Wilmore and Davis 1979, Arnold et al 1982). Justification for strength testing and subsequent allocation of manpower resources based on the results of such testing is documented by the work of Snook (Snook and Irvine 1969, Snook and Ciriello 1974, 1978) and Chaffin (1974, Chaffin et al 1978, Keyserling et all 1980a,b). These researchers demonstrated significant decreases in both musculoskeletal and contact injuries when employees worked within their strength capacity.

The uniqueness of military missions, the fitness characteristics and capacities of these personnel, and the nature of the criterion-strength task dictated additional studies of the US Army population. Thus the studies reported here were designed to 1) assess the lifting capacities of a sample of incumbents in a wide range of occupations, and 2) determine the relationship between these capacities and various simple, safe, and brief maximal isometric and isokinetic strength tests.

2. Methods

2.1 Subjects

Two hundred seventy two soldiers, 221 males and 51 females, assigned to various units of the 24th Infantry Division, Fort Stewart, GA, in the

Fall of 1979, volunteered to serve as subjects for this study. These subjects cannot be considered an overt random sample of US Army personnel, but rather an available sample of combat, combat support, and combat service personnel. All subjects were judged to be in good health and without any history of musculoskeletal or cardiovascular problems. Subjects' age, height (HT), weight (WT), lean body mass (LBM), and percent body fat (%BF) as estimated from four skinfold measures according to the formula of Durnin and Wormersley (1974) are presented in table 1.

[Insert table 1]

2.2 Procedures

2.2.1. Maximum safe lifting capacity (MSLC)

Subjects were asked to symmetrically lift a steel box (length 45 cm x width 31 cm x height 26 cm with taped and foam padded handles located 5 cm external and 15 cm above the bottom) from the ground to a flat surface 132 cm high. Subjects were required to use a flexed hip, straight back technique and a single smooth motion in lifting from the ground to the platform (Whitney, 1958). Although essentially all individuals had some manual materials handling experience, demonstrations and instruction of proper technique were provided to all subjects on an individual basis. All testing was conducted in an ambient thermal environment with the subject clothed in T-shirt, fatigue work pants, and combat boots.

Subjects were tested in groups of five individuals. All subjects began lifting an empty box (15.6 kg). Weights were added to the box in 1.2-11 kg increments depending upon the ease with which the previous weight was lifted. Subjects were allowed as much time as they desired between lifts (usually 2-3 minutes).

Four guidelines were used to determine when subjects had reached their safe maximums. The first was inability to actually place the weighted box onto the platform even when proper technique was used. The second was the observation of marked hyerextension of the trunk in an attempt to "angle" the edge of the box onto the lip of the platform. The third was degeneration of a single smooth evenly controlled lift into jerked disrupted segments. Lastly, deterioration of the straight back form into marked thoracolumbar flexion during the initial part of lift terminated further lifting.

No feedback as to the amount of weight lifted was provided the subjects although the number and size of iron weights in the box were not concealed. Subjects were almost invariably able to lift more weight if allowed to compromise the specified lifting form. When a subject was unable to lift the box using proper form, the previous weight lifted correctly (usually 2-2.5 kg less) was identified as the individual's MSLC.

2.2.2. Maximal dead lift (MDL) capacity

Upon determination of the MSLC, all female subjects and the first 64 males were tested for maximum dead lift (MDL) capacity. Inability to stand erect with the loaded box using a straight vertical back, squat posture, and no jerking was the criterion used to establish this

performance capacity. Only 64 males were tested since the maximum weight of the box was limited to 100 kg. All 64 males initially tested were capable of lifting this amount.

2.2.3. Maximal short term self-paced maximal lift-and-carry capacity

Following a one hour rest period, subjects were evaluated for self-paced maximal lift and carry capacity with loads of 25 and 43 kg. Subjects were required to lift the box previously described from floor to knuckle height, carry it five meters, and lower it to the ground. The number of carries completed with each weight after five (LC25/5, LC43/5) and ten (LC25/10, LC43/10) minutes was recorded. The ten minute values were used as the performance measures.

Subjects were instructed to make as many trips as possible while using proper form. Subjects were cautioned about the importance of pacing themselves even though the test would last only 10 minutes No incentives were offered other than verbal encouragement by the investigators such as, "Do the best job you can", "Try to make one more trip", "Keep it going", etc. Subjects performed this test in groups of three members of the same gender. At the conclusion of the first 10 minute bout subjects rested for 30 to 60 minutes then repeated the task at 43 kg.

2.2.4. Static strength measurement

Maximal voluntary isometric strength of various muscle groups was measured in six tests on a separate day. Force was registered with electromechanical transducers (load cells) and a digital indicator meter with peak and hold circuits (Baldwin, Lima Hamilton Corp., Waltham,MA,

USA). For all strength tests, subjects were instructed where to exert the force as well as the proper posture during the exertion. Subjects were asked to build to their maximal strength as rapidly as possible without jerking and to hold it until told to relax. The length of contraction was 4-5 seconds. If a subject produced a jerking motion during any phase of the contraction or if the force displayed on the digital readout did not indicate the expected progressive increase to the peak level, the contraction was repeated. At least three trials were given to each subject on each muscle group. If the difference in peak force recorded exceeded 10% then additional trials up to a total of five were given. One minute of rest separated each trial. The mean of the peak forces recorded for the three highest trials was taken as the strength score for each muscle group. Tests of difference muscle groups were separated by approximately five minutes.

Peak force measurements were recorded as opposed to the more reliable three second average force (Chaffin 1975). This decision was dictated by operational constraints in devising a test applicable to mass screening and requiring simple instrumentation.

The maximal voluntary isometric strength of upper torso (UT), leg extensor (LE), trunk extensor (TR), and handgrip (HG) muscles was measured on a device constructed in this laboratory (Knapik et al, 1979), but modified by replacement of cable tensiometers with electromechanical force transducers (BLH, Waltham, MA, USA). Handgrip strength was measured with the metacarpal-phalangeal joint of the index finger and the proximal interphalangeal joint at angles of 110 and 150 degrees respectively (Mundale 1970). In addition, maximal voluntary isometric strength was measured in an upward pulling position on a 4 cm

diameter adhesive-taped bar at heights of 132 cm (UP132) and 38 cm (UP38) (Knapik et al 1981). The distance between the ankles was adjusted by each subject from 25-42 cm with the distance in the sagittal plane from the ankles to the bar ranging from 10-20 cm depending upon the anatomical conformation of the individual subject.

2.2.5. Dynamic strength measurements

Trunk extensor strength was measured at velocities of 36 and 108 degrees per second using an isokinetic dynamometer (Cybex II, Lumex Corp, Ronkonkoma, New York). Subjects were positioned securely in an apparatus which stabilized the hips and thighs but allowed for extension of the trunk. The subject was coupled to the dynamometer lever arm with an 8 cm high, 50 cm wide padded cuff, the top of which was placed across the upper back 5 cm below the acromion process.

Subjects were allowed three familiarization contractions at each velocity followed by three separate maximal contractions (first at 36 degrees per second (CT36) and then at 108 degrees per second (CT108). Prior to each effort subjects were instructed to extend the trunk "as hard and as fast as you can" beginning at 90 degrees of trunk flexion and continuing until a full upright posture had been reached.

2.2.6. Physical fitness test performance

In addition to these laboratory measures the US Army Physical Readiness Test was administered on a separate day. The test consisted of 1) the maximum number of correct (i.e., elbow flexion reaching 90 degrees or greater) push-ups (PU) within two minutes (rest allowed in the front leaning rest position only), 2) the maximum number of bent-

knee (hands behind the head) sit-ups (SU) in two minutes (rest allowed with the upper torso in the upright position only), and 3) the time for a two mile run (TMR) on a level asphalt course. Approximately 20 minutes separated each of these tests.

Also conducted on a separate day was a test measuring heart rate during five minutes of bench stepping to predict the maximum oxygen uptake (VO2AR) using Astrand and Ryhming's method (1945, Astrand 1960, Margaria et al 1965,Shephard 1970).

2.3. Statistical methods

Means, standard errors of the mean (SEM), and ranges were calculated for all measures for each gender separately. Effects of gender were examined using analysis of covariance techniques. Male and female subjects were randomly assigned into two groups in order to address cross validation and multicollinearity issues using ridge regression methods (Hoerl and Kennard 1970a,b, Marquardt and Snee 1975). The effect and degree of bias used in the ridge regression process was subjectively evaluated in arriving at the final prediction equation for MSLC. Simple correlation measures were used to examine interrelationships of the independent measure with other criterion measures.

3. Results

3.1. Summary measures

Means, standard errors of the mean, and ranges for all strength, fitness, and lifting capacity measures are presented in table 2.

Reliabilities of the static and isokinetic strength measures, estimated using intraclass correlation techniques (Safrit 1976), were 0.97 (UT), 0.92 (LE), 0.83 (TR), 0.98 (HG), 0.96 (UP132), 0.97 (UP38), 0.98 (CT36), and 0.98 (CT108). Intercorrelational matrices for isometric, isokinetic, fitness, anthropometric, lift-and-carry, and MSLC measures are presented in table 3 for males and females separately, and in table 4 for both genders combined. Distributions for male and female MSLC performance are given in table 5.

[Insert tables 2-5]

3.2 Isokinetic, isometric, and fitness measures

In females the correlation between the isokinetic measures and the criterion measure, MSLC, was not significant at the 0.05% confidence level. The sample size precludes detection of a correlation less than 0.30. However, moderate correlations of 0.30 and 0.38 are noted between CT108 and CT36 respectively with the maximum dead lift (MDL) capacity. Much stronger correlations are noted between the isometric strength measures and MDL, ranging from 0.36 for UT to 0.68 for UP38. Similarly, correlations between isometric measures and MSLC are statistically significant for all but TR, varying from 0.36 to 0.52.

For males, correlations of the isokinetic measures with MSLC are moderate in degree, and suggest that an increase in sample size for females may demonstrate small to moderate correlations. All correlations between isometric measures and MSLC were statistically significant, although weak in the case of LE ($r=0.20$) and comparable in magnitude to the female correlations.

Correlations of the three fitness measures with MSLC for each gender were not significant at a 0.05% confidence level. This might be expected for the two mile run time, but is somewhat surprising for the sit-ups and push-ups performance measures. Again, in the case of the females it is not possible to detect weak to moderate correlations, and the demonstration of r=0.12 for sit-ups in males (just beneath the 0.05% confidence limit) suggests a real but weak correlation.

Correlations of these fitness measures with the repetitive lift-and-carry criteria (LC25/10 and LC43/10) are not statistically significant in females for all measures. Again, this lack of significance is due to poor statistical power in being able to detect correlations less than 0.30. The magnitude of these correlations in females generally parallels that of the males. In males both PU and TMR are statistically significant and comparable in their correlations with LC25/10 and LC43/10, although weak in magnitude. Combination of both PU and TMR results in multiple correlations of 0.25 and 0.29 with LC25/10 and LC43/10 respectively.

3.3. Gender effects

Analysis of covariance (ANCOVA) was conducted for one anthropometric measure and the six isometric measures using MSLC as the criterion variable and gender as the categorical variable. These variables were chosen for analysis as they represented potential and feasible measurements in an actual screening setting. Tests for parallel and coincidental behavior were done for each measure separately (Armitage 1971). The ANCOVA tests were done after separation of the sample population into the two cross validation groups. Results are presented in table 6, and figures 1-4 for LBM and three isometric measures.

[Insert table 6 and figures 1-4]

These results depict the expected lack of coincidence between males and females in their lean body mass characteristics and isometric strength performance. However there was no indication that the linear functional relationship between the various predictors and MSLC are different for males and females with the possible exception of LBM. Accordingly, these features support the utility of a single predictive model for both sexes with a gender designator as a constituent variable.

3.4. Prediction of maximal safe lifting capacity (MSLC)

Because of high intercorrelations among the independent or predictor variables, multicollinearity was expected to significantly influence the results of any multiple regression analysis in arriving at a usable prediction formula for MSLC. Accordingly, ridge regression methods as originally described by Hoerl and Kennard (1970a,b) and subsequently elaborated upon by Marqardt and Snee (1975) to encompass cross validation procedures, were used to compensate for multicollinearity effects.

Results of the initial ridge regression analysis for the two groups using gender, LBM, and the six isometric strength measures as predictors, demonstrated a 50-fold factor between the first and last eigenvalues of the correlation matrix thereby confirming significant multicollinearity effects. Three of the beta weights (LE, TR, and UP132) were driven relatively more rapidly to zero than the others with increasing magnitude of the biasing coefficient, k. They were eliminated, and the ridge regression procedure repeated with the reduced set.

Table 7 and figures 5 and 6 illustrate the results of the ridge regression for this reduced set of variables. Again, inspection of the eigenvalues suggests multicollinearity to be significant. Unrealistic negative beta weights for UP38 in group 1 and UT in group 2 were noted. The biasing process drives these beta weights to realistic positive values, markedly reducing the importance of LBM as a predictor in group 1, and suggesting that the three measures of isometric strength are of similar importance.

[Insert table 7, and figures 5 and 6]

Because of the face validity, a strong relationship to MDL as well as MSLC, simplicity of operation, and similarity to the test developed and validated by Chaffin (1975, Chaffin et al 1978), it was decided to retain only the UP38 isometric measure for the final predictive equation. The predictive model to be developed rests then on three variables - lean body mass, gender, and the 38 cm isometric upright pull.

Inspection of the beta weight plots as a function of the biasing coefficient suggested a value of 0.2-0.4 for the bias in group 1, and 0.0-0.2 for group 2. Plots of the cross validation residual standard deviation versus the biasing coefficient for the group 1 model demonstrated a minimum and suggested a coefficient of 0.05-0.2. A value of 0.0 for the group 2 model was similarly suggested.

As a result of these observations, values of 0.2 and 0.0 were chosen for the biasing coefficient for groups 1 and 2 respectively. Table 8 depicts the standardized regression coefficients for the two groups for the chosen values of the biasing coefficient, k. It is readily apparent

that the beta weights of group 2 are consistently greater in magnitude than those of group 1. However, the percentage of relative importance as calculated by the ratio of the square of the beta weight to the sum of squares of the weights are quite comparable.

[Insert table 8]

Squared correlations reflecting the estimator model R^2, the new sample R^2, and the cross validation or predictor, R^2 for both groups are also presented in table 8. Although the cross validation R^2 for the group 2 model is less than the expected new sample R^2 the difference does not significantly detract from the model.

The groups were combined to generate the final model. Table 9 presents the results of the ridge regression analysis. A 10 fold factor between first and third eigenvalues is equivocal in suggesting a multicollinearity problem. Without any bias the beta weights do not fall into the ranges suggested by the data in table 8. A bias of k=0.1 drives all the beta weights within the range suggested by the separate groups. This bias was chosen to generate the final MSLC model.

[Insert table 9]

Table 10 presents the final model coefficients for raw score scaled data for the prediction of the maximum safe lifting capacity from ground level to 132 cm and the standard error of the estimate.

[Insert table 10]

Prediction of the MDL capacity from a sample of 43 females using the two predictor variables chosen for the MSLC, LBM and UP38, without any biasing coefficient resulted in the equation MDL = 0.960xLBM(kg) + 0.46xUP38(kg) - 10.4. The standard error of the estimate was 9.58 kg and the multiple correlation coefficient was 0.72.

3.5. Repetitive lift-and-carry performance can be characterized in terms of strength and endurance capacity. Table 11 presents the results of the multiple regression analysis where the criterion measure is the number of repetitions over the ten minute period and independent variables are the MSLC and the maximal oxygen uptake (VO2AR) calculated from step test heart rate data.

[Insert table 11]

The highest correlations with the lift-and-carry performance at both weights are with the MSLC. All multiple R's are significant at the 0.01 confidence limit although they are moderately weak with the exception of the female 43 kg lift-and-carry performance which was R=0.64. The addition of VO2AR significantly increases the amount of variance accounted for by the regression model, although the increase is not large.

Figure 7 illustrates the decline in performance comparing the 25 kg and 43 kg loads as related to the percentage of MSLC and MDL for each gender. The 10 minute performance decrements of 45% and 59% in males and females, respectively, are noted with the 72% increase in weight. Female performance at both loads averaged 46% that of males. In both

sexes the work rate dropped from the first five minute period to the second - 21% and 23% for males, and 26% and 19% for females at the 25 kg and 43 kg loads, respectively.

[Insert figure 7]

4. Discussion

4.1 Distribution of strength measures, and gender effects

Median performances for males and females in lifting a weighted box from the ground to a 132 cm platform are 57.1 kg and 31.1 kg respectively. These compare to median predicted lifting strengths using a static biomechanical model (Martin and Chaffin 1972 as summarized in Garg and Ayoub 1980) of 51 kg and 23 kg for males and females respectively. Although the criterion tasks of this paper and that of Martin and Chaffin (1972) are not strictly comparable, it would appear that females tested in this study are significantly stronger. This would be consistent with the youth, health, and physical training status of the female US Army sample.

Median MSLC performance in males is 1.8 times that of females, while, for all but one, median isometric measures in males vary from 1.5 to 1.6 times that of females. Thus, at a given level of isometric performance males appear to be able to produce greater levels of isotonic performance than females. This finding is consistent with Poulsen's (1970) findings that men were able to dead lift 8-10 kg more

than women at identical levels of maximum isometric back strength capacity. While this may reflect real physiologic differences between genders, psychologic and experiential explanations as well as differential biased ascertainment of maximum performance on the criterion task by the investigators cannot be ruled out. However, the male/female median isokinetic ratios of 1.8 for both measures are directly comparable to the MSLC ratio, and would suggest physiologic, experiential, or psychologic differences between males and females in explaining differential maximum isometric strength performance relative to a given level of performance on the criterion task (MSLC).

4.2 Isometric and isokinetic correlations with MSLC and MDL

Isometric measures are more highly correlated with MSLC in both genders and MDL in females than isokinetic measures. This finding would be consistent with the interpretation that the criterion measures approach the limiting conditions characteristic of isometric performance, and thereby tend to reflect isometric capability. Demonstration of higher correlations of the slower speed isokinetic measure with MSLC in males and MDL in females as compared with the higher speed measure is consistent with this interpretation.

Correlations of the isometric measures with MSLC and MDL in females indicate stronger correlations in general with MDL. This finding probably reflects the greater simplicity of the MDL task compared to the MSLC task, and thereby a relatively more precise measure.

4.3. Prediction of MSLC

The use of ridge regression techniques to generate a predictive equation for MSLC results from complications associated with multicollinearity. Without the use of the ridge method a quantitative equation may be derived which is unrepresentative of the true population functional relationship. Similarly, one may also select predictor variables that do not reflect the best determinants of the MSLC.

The ridge regression process demonstrated that three isometric measures of strength were comparable in their utility as predictors of MSLC. Upright pull at 38 cm was chosen as the single isometric strength measure for the final model for logistic and operational reasons. However, upper torso and handgrip isometric strength measures would appear to be of similar utility. Comparison of these isometric tests as predictors of MSLC with research of other investigators is compounded by problems of comparability. Chaffin's (Chaffin et al 1978) approach correlated isometric measures of limb and torso strength with isometric strength in specific job task positions. Poulson (1970) examined only the relationship of isometric back strength to an isotonic dead lift criterion. Garg and Ayoub (1980) used isometric measures of job position strength as correlates of "dynamic lifting capability". In all these cases differences in comparability of both the isometric measures and the criterion task detract from contrasting published results.

The use of a gender designator in the predictive equation demands some comment. The final beta weight for gender indicates that only 8% of the variance accountable by the model is derived by the gender variable. Thus, gender designation in the model "accounts" for only 5%

of the total variance in the MSLC measure. However, a simple linear regression using only gender would account for over 50% of the total variance in MSLC. The high intercorrelation between gender, lean body mass, and MSLC results in the somewhat misleading impression that an anthropometric measure, LBM, accounts for an extensive proportion of the total variance in MSLC. Since gender also is a determinant in how LBM is calculated from skinfold measures of adiposity, and true biologic differences exist between the genders for degree of adiposity and size, then the actual role of LBM as a determinant of MSLC is probably exaggerated in this model - a proportion of the LBM measure actually being a surrogate for gender. This is not to say LBM accounts for little of the variance; rather, its effect is probably overestimated by these data.

Use of this predictive equation and its variance characteristics to screen enlistee populations or civilian industrial populations may give misleading results. This sample of incumbent male and female soldiers may not necessarily be representative of inductees or a civilian work force with respect to age, fitness level, or body habitus. The model probably can be used for point prediction without fear of bias in populations with different distribution characteristics. However, use of its probability characteristics for screening, or its distribution characteristics for enlistee manpower description and allocation should be avoided.

4.4. Repetitive lift-and-carry performance

Multiple regression analysis of this task confirms the importance of

both strength and endurance components. Large correlations cannot be expected in these data for three reasons. First, no reward system was used to enhance motivation. Secondly, the stepping test is an indirect and imprecise measure of aerobic capacity. Lastly, 10 minutes of maximal lift-and-carry performance tends to be dominated by strength capacity, although aerobic capacity would be expected to play some role in task performance. The strong correlation between LC43/10 and MSLC in females suggests that strength capacity alone plays a more significant role in repetitive lifting and carrying of a relatively heavy external mass.

It would appear that even relatively fit female soldiers are excessively stressed by the ten minute 43 kg lift-and-carry task. Although all but one of the female subjects were capable of dead lifting this weight, the median percent of MDL capacity exceeds 50%. Jorgensen and Poulsen (1974) demonstrated that exceeding 50% of the maximum lifting capacity will not increase work output per unit time in a repetitive lift-and-carry task. Similarly, injury rates significantly increase beyond this limit - especially for tasks of longer duration (Chaffin and Park 1973, Chaffin et al 1978).

Although not quantitatively addressed in this study, endurance capacity was a significant determinant in performance of this repetitive lift-and-carry task. Petrofsky and Lind (1978b) demonstrated in a laboratory setting that repetitive lifting tasks can be maintained for one to four hours when subjects work at no more than 50% of their maximum oxygen uptake measured for lifting each specific weight of box. Measures of maximum oxygen uptake in lifting modes of exercise appear to be limited by local fatigue factors, and are directly correlated to the weight being lifted (Petrofsky and Lind 1978a). Thus, it is suggested

that correlations between lift-and-carry performance and maximum safe lifting capacity (MSLC) may reflect both pure strength determinants as well as oxygen utilization capacity. These measured correlations could be mediated by both the biologic effects described by Petrofsky and Lind (1978a,b) as well as population characteristics reflecting positive intercorrelations between high strength capacity and high aerobic capacity (i.e., in a general population, strong people tend to be more aerobically fit).

4.5. Fitness test performance and manual materials handling capability

Inasmuch as manual materials handling tasks demands have been used to classify US Army occupations for entrance screening, it is interesting to note the moderately poor correlations of any fitness test measure, alone or in combination, with these single and repetitive lifting criteria. Based on these data it would appear advisable for the US Army to consider new, or modify conventional, physical testing and training programs to better assess and develop the strength and anaerobic capacity which are most clearly related to critical military physical tasks.

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TABLE 1

Subject age, height, weight and estimated body composition

	Males			Females		
	n	228			51	
	$\bar{X}$	SEM	Range	$\bar{X}$	SEM	Range
Age	21.1	0.2	17-30	22.3	0.4	18-31
Height (cm)	176.1	0.5	159-197	165.2	0.9	152-182
Weight (kg)	73.7	0.6	53-104	62.8	1.3	49-86
Lean Body Mass (kg)	62.6	0.4	46-85	45.0	0.7	37-58
Body Fat (%)	15.4	0.3	8-27	28.0	0.8	17-39

TABLE 2

Static and dynamic strength, physical readiness test scores, lifting and lift-and-carry capacities. Static measures are presented in units of newtons and kilograms.

	Males			Ratio	Females		
	$\bar{X}$	SEM	Range	Female/Male	$\bar{X}$	SEM	Range
UT (N)	1052.5	1.1	59-153	.55	576.2	2.1	24-115
(kg)	107				58.8		
LE (N)	1642.5	3.1	75-297	.61	997.1	3.9	48-169
(kg)	167.6				99.3		
TR (N)	784.0	1.2	32-129	.64	502.7	1.8	26-78
(kg)	80.0				51.3		
HG (N)	529.2	0.6	35-83	.63	334.2	0.9	25-55
(kg)	54.0				34.1		
UP132(N)	572.3	1.0	23-108	.66	375.3	1.4	22-66
(kg)	58.4				38.3		
UP38(N)	1352.4	1.7	55-202	.61	820.3	2.7	49-131
(kg)	138.0				83.7		
CT36(N-M)	286.3	5.2	140-487	.57	162.1	7.0	80-270
CT108(N-M)	223.7	5.5	77-435	.57	126.4	6.2	38-212
PU (reps)	48.5	0.9	23-112	.52	25.2	1.9	6-50
SU (reps)	42.4	0.9	13-84	.81	34.3	21.0	10-65
TMR (sec)	982.1	9.3	724-1408	1.38	1354.0	27.4	931-
MSLC (kg)	57.6	7.1	34-100	.55	31.9	0.8	22-46
MDL (kg)					72.1	23.0	41-100
LC25/5(reps)	37.2	0.5	23-62	.64	23.7	0.6	16-34
LC25/10(reps)	66.7	0.9	40-109	.62	41.2	1.2	26-59
LC43/5(reps)	20.6	0.3	8-40	.46	9.4	0.6	2-23
LC43/10(reps)	36.6	0.6	14-68	.46	17.0	1.0	6-38

TABLE 3

Pearson product moment correlation coefficients for strength, body composition, fitness test scores, and lifting capacities: above the diagonal for the male subjects and below the diagonal for females

	HT	WT	%BF	LBM	SU	PU	TMR	UT	LE	TR	HG	UP132	UP38	CT36	CT108	MSLC	LC25/10	LC43/10
HT		.44	-.17	.58	.08	-.24	-.03	.18	-.06	-.13	.36	.24	.17	.30	.27	.46	.07	.05
WT	.29		.46	.90	.10	.02	.18	.48	.26	.31	.52	.36	.50	.59	.41	.66	.23	.24
%BF	-.13	.58		.04	.01	-.02	.33	.07	.08	.13	-.03	.01	.11	.12	.04	.04	.01	-.08
LBM	.44	.84	.05		.11	.03	.04	.51	.25	.29	.61	.41	.52	.62	.44	.72	.26	.32
SU	-.17	-.23	-.32	-.06		.30	-.07	.25	.08	-.10	.06	.05	.11	.21	.26	.12	.04	.09
PU	-.52	-.52	-.51	-.29	.54		-.09	.31	.15	.18	.10	.17	.19	.27	.25	.02	.17	.23
TMR	-.39	.23	.57	-.09	-.33	-.15		.01	.06	.09	.02	-.03	-.01	.06	.05	-.01	-.20	-.19
UT	-.06	.42	-.08	.60	.22	.11	-.14		.17	.49	.52	.44	.59	.52	.39	.49	.35	.40
LE	-.18	.58	.55	.34	-.11	-.20	.34	.26		.13	.16	.25	.35	.22	.10	.20	.07	.15
TR	.23	.57	.30	.49	-.08	-.37	-.08	.37	.38		.30	.35	.47	.29	.17	.27	.45	.43
HG	.10	.54	.07	.61	.31	.04	.03	.58	.44	.41		.42	.55	.44	.32	.52	.28	.34
UP132	-.05	.50	.29	.40	.11	-.12	-.08	.43	.54	.56	.43		.59	.45	.45	.35	.22	.23
UP38	.07	.48	.11	.52	.22	.04	-.14	.62	.48	.45	.70	.72		.48	.37	.49	.35	.37
CT36	.06	.44	.26	.36	.10	-.35	.00	.36	.50	.70	.34	.57	.40		.85	.43	.14	.23
CT108	-.07	.24	.16	.18	.13	-.27	.05	.13	.24	.53	.21	.47	.25	.81		.23	-.01	.09
MSCL	.13	.56	.12	.62	.11	-.03	-.04	.52	.36	.28	.48	.36	.51	.29	.27		.33	.32
LC25/10	.12	.06	-.18	.19	.12	.20	-.23	.19	.18	.04	.38	.32	.58	-.11	-.11	.12		.73
LC43/10	.18	.47	.07	.53	.09	.05	-.26	.29	.37	.33	.50	.44	.62	.17	.11	.54	.68	

Levels of significance	Males	Females
$p < 0.05$	$r = 0.13$	$r = 0.30$
$p < 0.01$	$r = 0.18$	$r = 0.42$
$p < 0.001$	$r = 0.23$	$r = 0.51$

TABLE 4

Pearson product moment correlation coefficients for strength, body composition, fitness test scores, and lifting capacities for males and females combined.

HT	WT	%BF	LBM	SU	PU	TMR	UT	LE	TR	HG	UP132	UP38	CT36	CT108	MSLC	LC25/10	LC43/10	
1.00	.55	-.47	.70	.15	.10	-.37	.47	.20	.23	.56	.41	.45	.48	.42	.63	.35	.37	HT
	1.00	-.03	.87	.14	.21	.14	.61	.44	.50	.64	.51	.62	.67	.51	.71	.41	.47	WT
		1.00	-.52	-.19	-.48	.65	-.53	-.28	-.35	-.52	-.34	-.46	-.34	-.31	-.50	-.44	-.49	%BF
			1.00	.22	.41	-.43	.78	.51	.59	.80	.60	.76	.74	.59	.86	.57	.64	LBM
				1.00	.39	-.22	.32	.15	.05	.21	.16	.23	.28	.31	.23	.16	.20	SU
					1.00	-.41	.58	.36	.41	.45	.39	.50	.46	.41	.41	.45	.49	PU
						1.00	-.46	-.24	-.31	-.41	-.33	-.44	-.30	-.24	-.44	-.49	-.51	TMR
							1.00	.47	.69	.77	.63	.80	.69	.55	.76	.62	.67	UT
								1.00	.39	.45	.45	.57	.45	.31	.48	.34	.42	LE
									1.00	.58	.55	.68	.54	.40	.57	.62	.63	TR
										1.00	.61	.77	.64	.51	.75	.57	.63	HG
											1.00	.72	.61	.58	.57	.45	.48	UP132
												1.00	.66	.55	.74	.62	.65	UP38
													1.00	.88	.64	.41	.49	CT36
														1.00	.47	.26	.35	CT108
															1.00	.60	.63	MSLC
																1.00	.82	LC25/10
																	1.00	LC43/10

$p < 0.05$ for $r > 0.13$

$p < 0.01$ for $r > 0.18$

$p < 0.001$ for $r > 0.21$

TABLE 5

Percentile distribution for maximum safe lift capacity, ground to 132 cm, for males and females. Values are kilograms.

Male	Percentile	Females
38.50	1	22.30
38.90	5	22.30
43.50	10	24.90
48.00	20	27.30
52.40	30	29.10
54.90	40	29.20
57.10	50	31.10
61.50	60	31.70
61.60	70	33.90
66.20	80	36.20
70.70	90	40.00
72.90	95	41.20
87.00	99	45.60
57.10	Median	31.10
57.02	Mean	31.75

TABLE 6

Test for parallel and coincidental behavior using t test
Comparisons are between sexes in the same group

	Group 1				Group 2			
Variable with MSLC	n_1	n_2	t_p	t_c	n_1	n_2	t_p	t_c
LBM	21	92	1.54	1.54	22	90	1.60	3.97**
LEG	21	92	0.53	7.90**	22	91	0.7	8.88**
TR	21	91	0.49	7.27**	22	91	0.12	8.44**
UT	21	92	1.36	3.04**	22	91	0.15	4.10**
HG	21	92	0.90	3.94**	22	91	0.32	5.54**
UP38	21	92	0.76	3.7*	22	91	0.40	6.60**
UP132	21	92	0.04	7.04**	22	91	0.03	9.19**

* significant at $p<0.05$

** significant at $p<0.01$

TABLE 7

Eigenvalues and unbiased standardized regression coefficients for the prediction of MSLC from LBM, UT, HG, UP38, and gender

Group 1 model

variable	βweight	eigenvalue	degree
LBM	0.674	4.092	1
UT	0.186	0.315	2
HG	0.033	0.228	3
UP38	-0.002	0.196	4
Gender	-0.034	0.168	5

Group 2 model

variable	βweight	eigenvalue	degree
LBM	0.526	3.990	1
UT	-0.047	0.379	2
HG	0.138	0.305	3
UP38	0.182	0.189	4
Gender	-0.199	0.136	5

TABLE 8

Standardized regression coefficient and squared multiple correlation coefficient for two models of MSLC

Model group:	1	2		1	2
k	0.2	0.0	Estimation R^2	0.754	0.817
beta weights:					
LBM	0.514	0.583	New sample R^2	0.738	0.805
UP	0.180	0.205			
Gender	-0.152	0.199	Predictor R^2	0.804	0.760

TABLE 9

Eigenvalues and standardized coefficients for a single combined group model of MSLC.

Variable	R^2 = 0.790 β weight @ k = 0.0	R^2 = 0.785 β weight @ k = 0.1	eigenvalue	degree
LBM	0.546	2.456	2.456	1
UP_{38}	0.145	0.191	0.324	2
Gender	-0.138	-0.175	0.220	3

TABLE 10

Multiple correlation coefficient, standard error of the estimate (SEE), and sample size for combined groups data for the prediction of MSLC in kg. (males = 1, females = 2 for SEX)

$R = 0.89$

$SEE = 6.61$ kg, $n = 225$, $n_f = 43$, $n_m = 182$

$$MSLC = -8.466 + 0.9933\ (LBM) + 0.006349\ (UP\ 38) - 4.777\ (SEX)$$

TABLE 11

Regression analysis for the prediction of lift and carry performance at two loads for each gender separately from MSLC and VO2AR predictors

43 Kg carryover 10 ft. for males (n = 182 and females (n = 42)

		males		females	
step	variable	simple r	multiple R	simple r	multiple R
1	MSLC	0.335	0.335	0.602	0.602
2	VO2AR	0.129	0.357	0.173	0.640

25 kg carryover 10 ft. for males (n = 182) and females (n = 42)

		males		females	
step	variable	simple r	multiple R	simple r	multiple R
1	MSLC	0.322	0.322	0.306	0.306
2	VO2AR	0.153	0.353	0.036	0.312

Figure Legends

Figure 1. Scatter diagram and regression analysis showing the relationship between maximal safe lift capacity to 132 cm and lean body mass

Figure 2. Scatter diagram and regression analysis showing the relationship between maximal safe lift capacity to 132 cm and hand grip force.

Figure 3. Scatter diagram and regression analysis showing the relationship between maximal safe lift capacity to 132 cm and upper torso pull down force at 132 cm.

Figure 4. Scatter diagram and regression analysis showing the relationship between maximal safe lift capacity to 132 cm and upright pull force at 38 cm.

Figure 5. Results of the ridge regression in Group I on five variables. Lines represent variation of standardized regression coefficients plotted against bias.

Figure 6. Results of the ridge regression in Group II on five variables. Lines represent variation of standardized regression coefficients plotted against bias.

Figure 7. Repetitive lift-and-carry performance as a function of percent of maximum dead lift capacity or maximum safe lift capacity for males and females at 25 kg and 43 kg loads.

Figure 1.

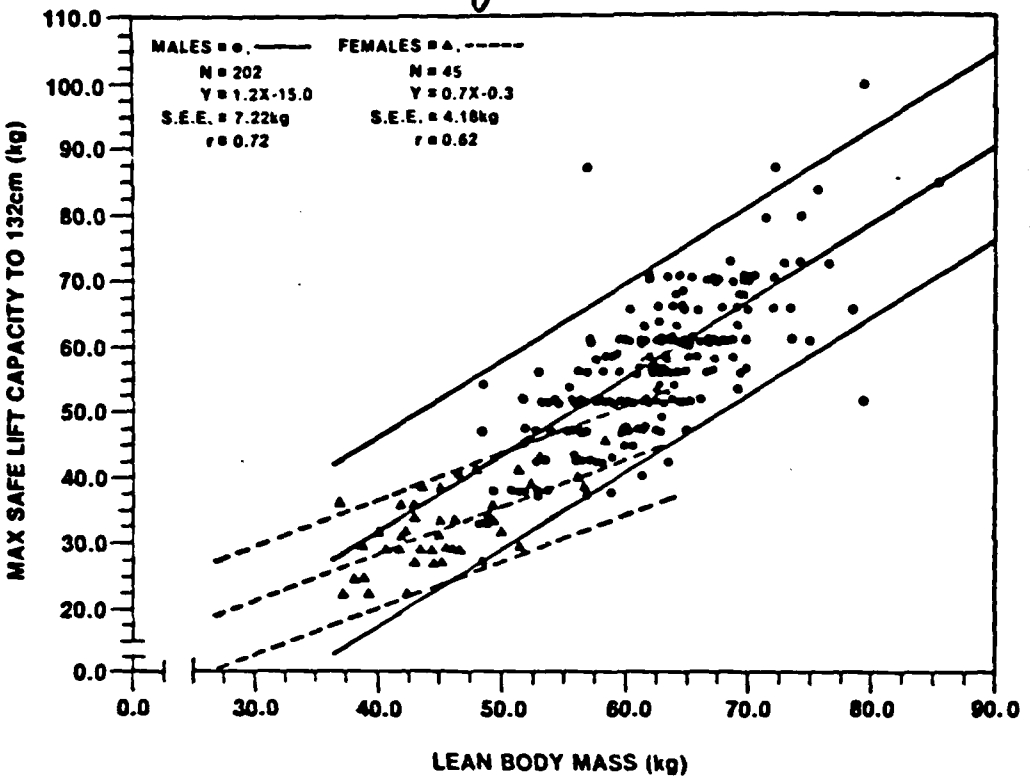


Figure 2.

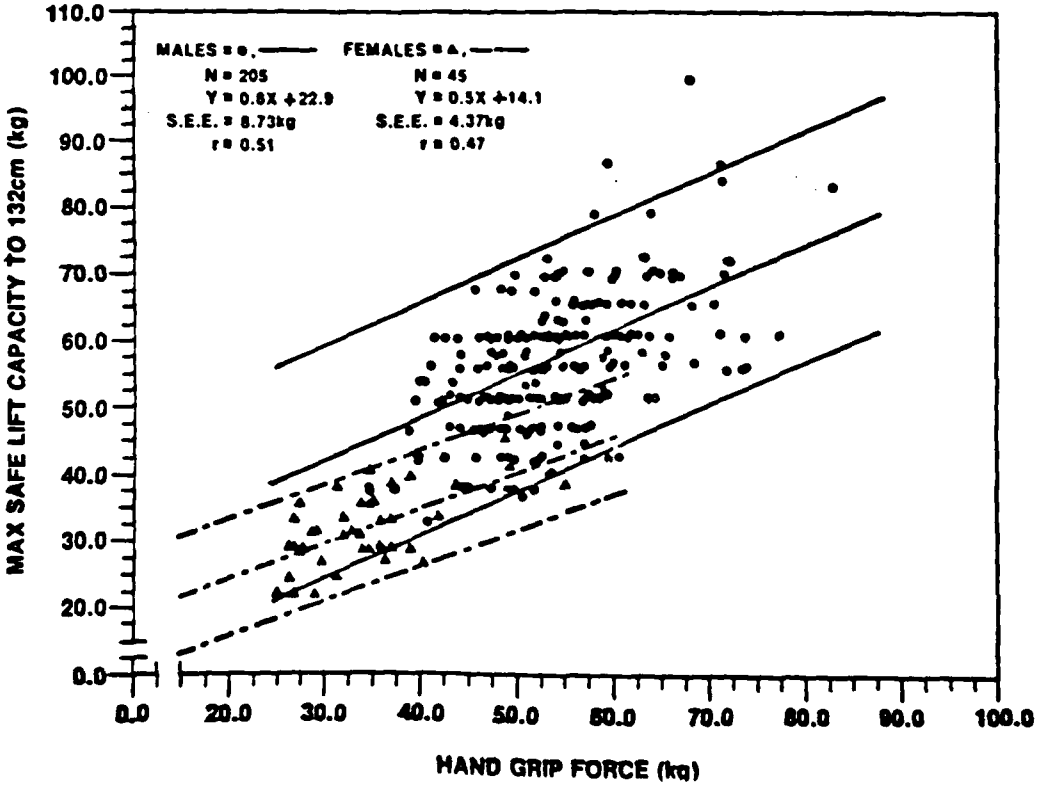


Figure 3

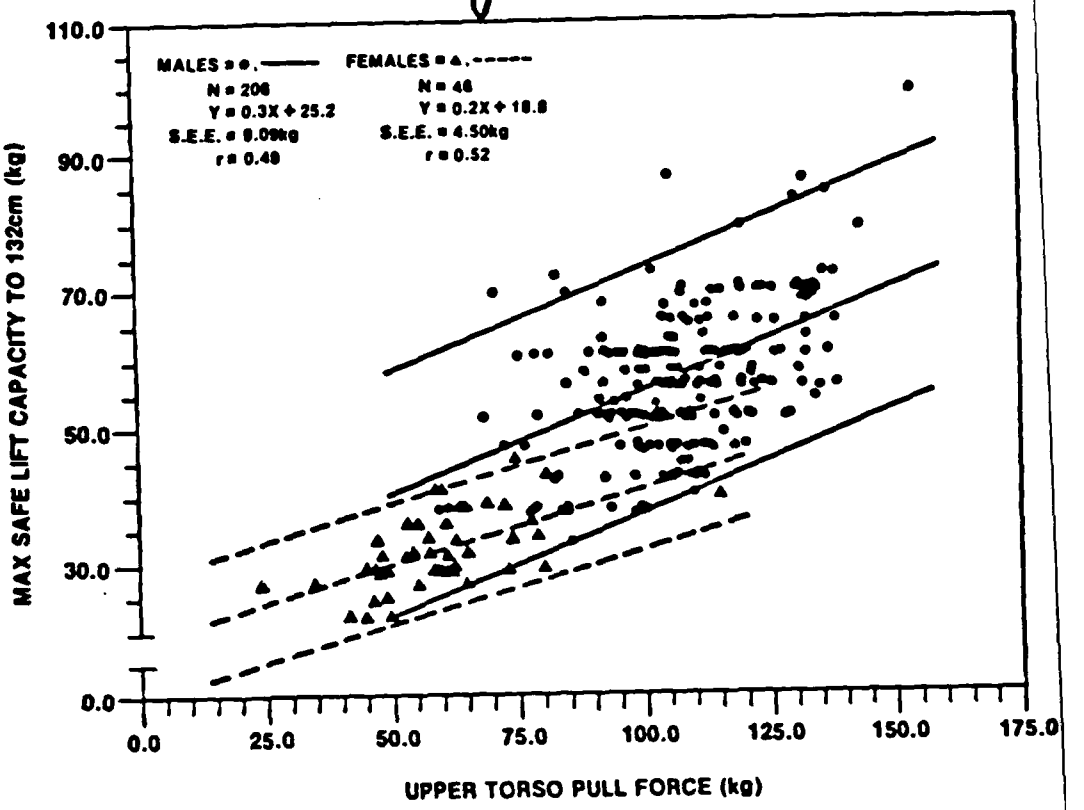


Figure 4

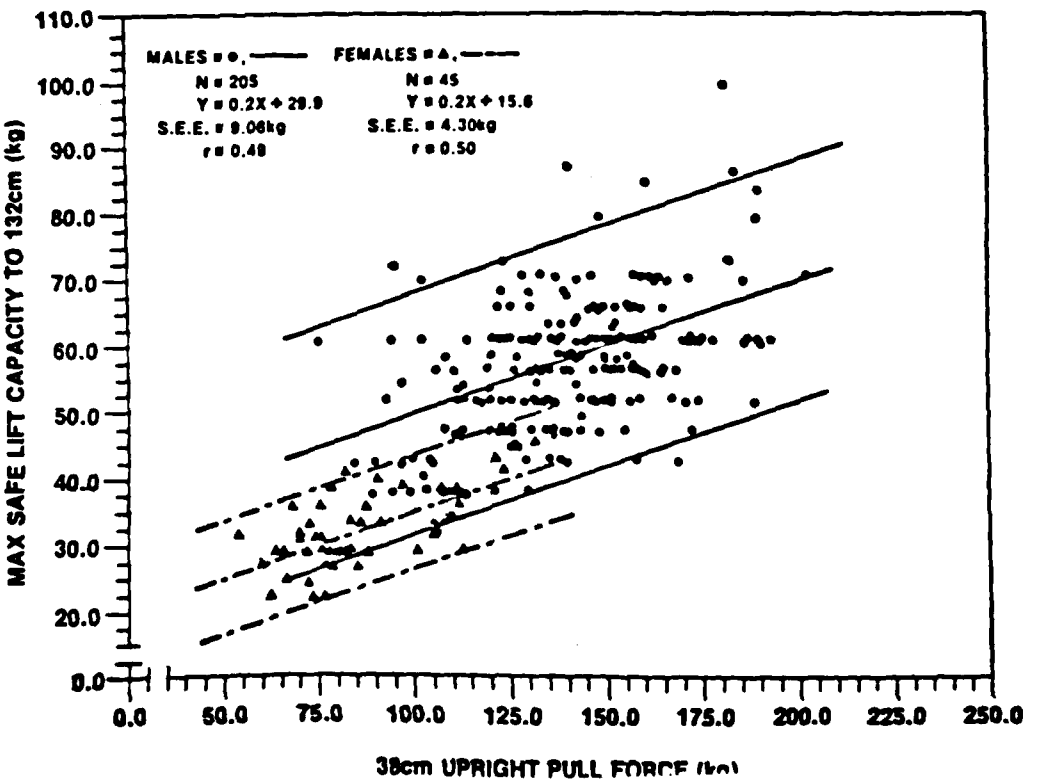


Figure. 5

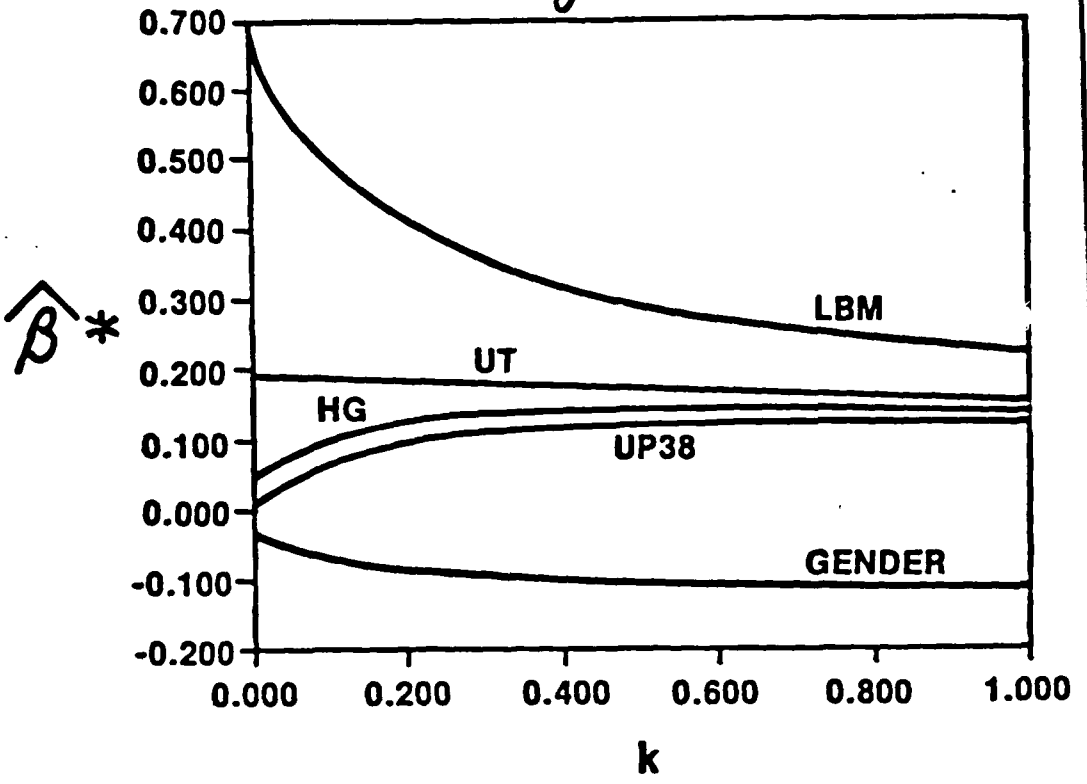


Figure 6

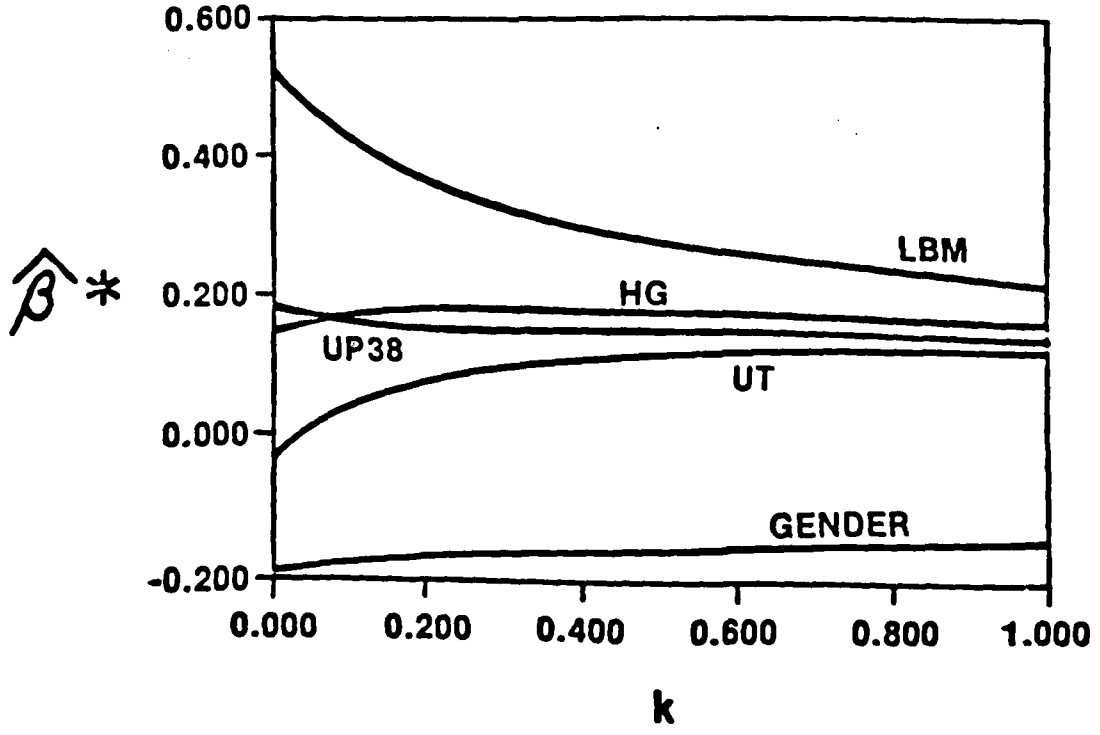
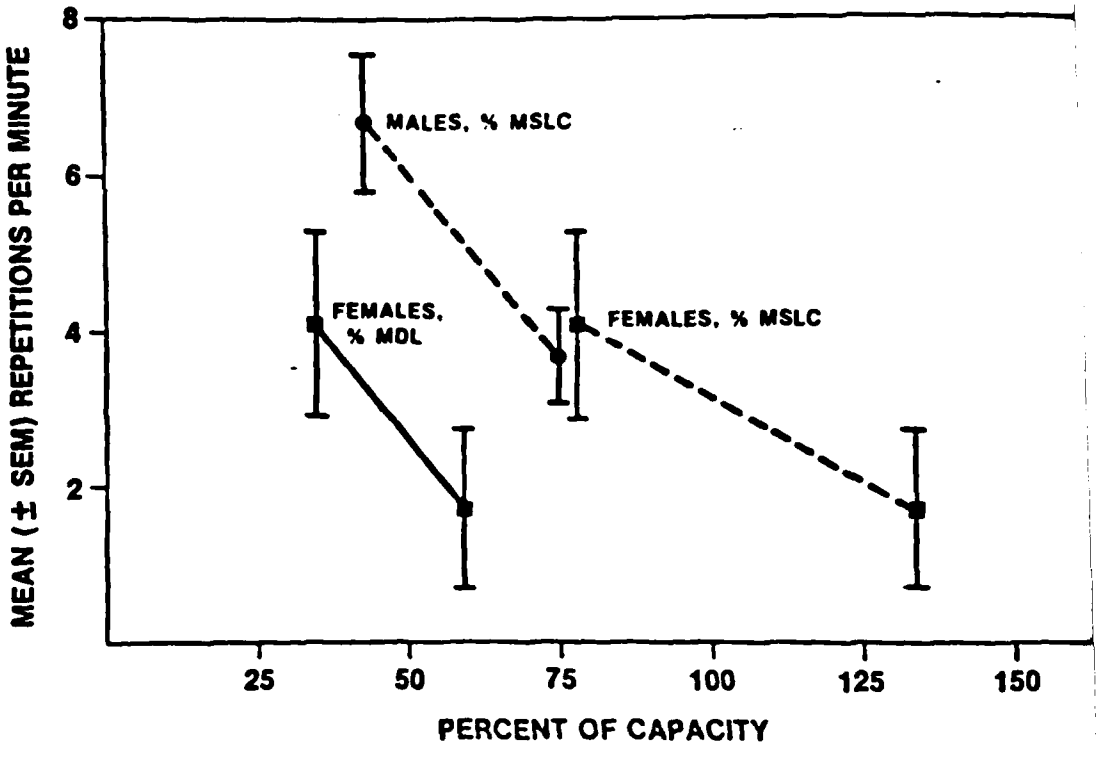


Figure 7


MEAN (± SEM) REPETITIONS PER MINUTE
8
6
4
2
MALES, % MSLC
FEMALES, % MDL
FEMALES, % MSLC
25
50
75
100
125
150
PERCENT OF CAPACITY