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Less Body Fat Improves Physical and Physiological Performance in Army Soldiers

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ABSTRACT The purpose of this study was to compare physical and physiological fitness test performance between Soldiers meeting the Department of Defense (DoD) body fat standard (≤18%) and those exceeding the standard (>18%). Ninety-nine male 101st Airborne (Air Assault) Soldiers were assigned to group 1: ≤18% body fat (BF) or group 2: >18% BF. Groups 1 and 2 had similar amounts of fat-free mass (FFM) (66.8 ± 8.2 vs. 64.6 ± 8.0, p = 177). Each subject performed a Wingate cycle protocol to test anaerobic power and capacity, an incremental treadmill maximal oxygen uptake test for aerobic capacity, isokinetic tests for knee flexion/extension and shoulder internal/external rotation strength, and the Army Physical Fitness Test. Results showed group 1: ≤18% BF performed significantly better on 7 of the 10 fitness tests. In Soldiers with similar amounts of FFM, Soldiers with less body fat had improved aerobic and anaerobic capacity and increased muscular strength.

INTRODUCTION

In 1976, the Army Weight Control Program 600-9[1] (AR 600-9) underwent a significant revision, which resulted in combining the U.S. Army Physical Fitness and Weight Control Program regulations in response to concerns that Army personnel were becoming too sedentary, fat, and unable to maintain desired levels of physical fitness.[1] The primary objective of the AR 600-9 is to ensure that all Army personnel are able to meet the physical demands of their duties under combat conditions. It is a mandatory weight control program that uses body weight and percent body fat (% BF) to assist in establishing and maintaining health, optimal physical fitness, and operational readiness.[1]

There is great debate, however, over ideal body composition for military personnel to optimize physical fitness and performance on the battlefield. Identifying "ideal" body composition standards in military personnel is complicated by the diverse, multifaceted requirements of military training and missions. Unlike elite strength/power athletes who benefit from a higher body weight and greater lean body mass and elite endurance athletes who benefit from carrying less body weight and low fat mass, the tactical athlete engages in military training and missions that require adeptness in both of these fitness areas. Given these requirements, it appears that a large, lean body composition with less body fat would best meet the demands of military performance. The difficulty lies in the fact that the Army is recruiting from an American population that is 68% overweight/obese;[2] of this population, more than 9 million adults aged 17 to 24 are too overweight to join the military.[3] "Today's Soldiers are larger than ever before, a desirable Army trait—"large and in charge"—with appearance of fitness and formidable size."[4]

Scientific evidence, however, is equivocal regarding the impact a larger body size has on physical fitness and military performance in the contemporary Soldier. Research substantiates that excess body weight as fat-free mass (FFM) will improve performance on standardized strength tests, as well as physical tasks involving carrying and lifting.[5,6] If, however, the strength tests require moving body mass through space or if body mass serves as the external load, lean body mass is not associated with increased muscle strength performance.[7] Mattila et al.[8] found that lean body mass was not associated with muscle strength measured by standing long jump, push-ups, sit-ups, pull-ups, and back extension.[8] Additionally, because muscle mass does not proportionately increase with body mass, larger individuals may be at a disadvantage in maneuvering their own bodies.[9]

Excessive total body mass has been associated with impaired aerobic fitness[4] and performance on a variety of military readiness tests.[8,10–12] If excess weight is predominantly fat mass, research is consistent that higher % BF does not optimize fitness or performance.[8,10,11,13] A prospective study of 140 Army recruits showed that a 1% increase in fat shortened the 12-minute running distance by 19.3 meters.[8] Moreover, higher % BF has been shown to negatively affect military performance on tasks that require both strength and aerobic components such as loaded marching.[6,14]

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A report from the Armed Forces Health Surveillance Center revealed a drastic rise from approximately 25,000 to 70,000 active component military service members diagnosed as overweight between 1998 and 2008.[15] Given the ambiguity between "overweight" and "overfat," research is warranted to investigate whether there is an appropriate % BF that would significantly improve strength, aerobic, and anaerobic fitness compared to those with a higher % BF, regardless of total body weight.

The purpose of this study was to compare performance on physical and physiological tests between Soldiers meeting the Department of Defense (DoD) body fat goal (≤18%) and those exceeding the goal (>18%). It was hypothesized that male Soldiers with less % BF (≤18%) would perform better on physical and physiological fitness tests and the Army Physical Fitness Test compared to Soldiers with higher % BF (>18%).

METHODS

Subjects

Ninety-nine male subjects were recruited from the Army 101st Airborne Division (Air Assault) to participate in this study. Approval was obtained from the University of Pittsburgh's Institutional Review Board, Eisenhower Army Medical Center, Clinical Investigation Regulatory Office, and the Human Research Protection Office as part of an ongoing research project focusing on injury prevention and performance optimization in the 101st Airborne Division (Air Assault).

Dependent Variables

Body composition, measured as % BF, was used to categorize subjects into groups on the basis of DoD body fat goals:[16] group 1: ≤18% BF and group 2: >18% BF. Physiological variables included anaerobic power (PNAP) and anaerobic capacity (MNAP); maximal oxygen consumption (VO_2max); peak isokinetic knee extension (AKE) and flexion (AKF); peak isokinetic shoulder internal (ASIR) and external rotation (ASER); and the Army Physical Fitness Test (APFT). Laboratory testing was performed in the Research Center for Injury Prevention and Human Performance at Fort Campbell by the same research associates on 2 separate days, with at least 24 hours separating each test day. Body composition, isokinetic strength tests, and anaerobic capacity were tested on day 1 and VO_2max was performed on day 2. The components of the APFT were performed on the same day on a separate occasion in a field setting. Although the primary purpose of the tests was to assess the Soldiers' strength and aerobic and anaerobic fitness, achieving and maintaining a high level of each fitness component is critical for Soldiers' combat survivability and overall operational effectiveness.[17,18]

Body Composition

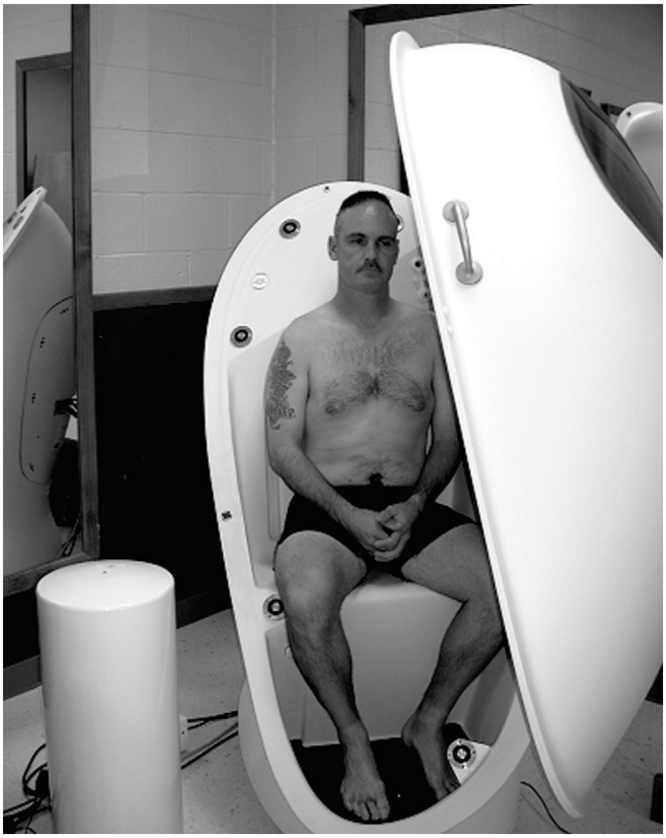

FIGURE 1. Body fat analysis.

The Bod Pod Body Composition System (Life Measurement Instruments, Concord, California; see Figure 1) was used to measure body composition. The Bod Pod utilizes air-displacement plethysmography to measure body volume and calculate body density. The Bod Pod is a valid method of body composition measurement in comparison with the gold standard, hydrostatic weighing, in heterogeneous samples, and has been used to assess body composition across a variety of populations.[19–24] Intrasubject reliability within our laboratory has demonstrated reliability and validity (ICC = 0.98, SEM = 0.47% BF). The system underwent a standard calibration utilizing a 50.683 L calibration cylinder and an additional two-point calibration before each test. Subjects wore spandex shorts and swim caps. Body volume was measured until two consistent measurements were achieved. Predicted lung volume and an appropriate densitometry equation were used to calculate % BF.[25] Subjects were assigned to group 1: ≤18% BF or group 2: >18% BF to compare the results on the following physiological fitness tests.

Anaerobic Power

Anaerobic power and capacity were measured using a VeloTron cycling ergometer (RacerMate, Seattle, Washington; see Figure 2) during a Wingate protocol.[26] The Wingate protocol is highly valid and reliable[27] and has been significantly correlated with anaerobic run test performance.[28,29] The ergometer was calibrated by pedaling to a velocity according to factory recommendations. Proper seat and handlebar adjustments

FIGURE 2. Wingate test.

FIGURE 3. Maximal oxygen uptake test.

were made before the subject's feet were secured to the pedals, and a warm-up cycle at a self-selected cadence was initiated at 125 watts (W). Subjects underwent a 50-second cycling protocol, in which they pedaled at 125 watts for 20 seconds, and then performed a maximal effort sprint for 30 seconds against a braking torque of 9% body weight. Standard verbal instructional cues were provided during the test. Anaerobic power was reported as the peak watts normalized to body weight produced during the first 5 seconds of the test, and anaerobic capacity was reported as the average watts normalized to body weight produced during the entire 30 seconds (W/kg).

Maximal Oxygen Uptake

A portable metabolic system (Oxycon Mobile; Viasys, San Francisco, California; see Figure 3) was used to assess maximal oxygen consumption during an incremental treadmill test. The Oxycon Mobile is a valid metabolic system, showing less than 3% difference compared to simulated VO_2 during a maximal cardiopulmonary exercise test.[30] The instrument was calibrated with known gas mixtures and measured values corrected to standard temperature, pressure, and density. A heart rate monitor (Polar USA, Lake Success, New York) was worn by the subject around the chest at the level of the zyphoid process. The subject performed a warm-up at a self-selected speed on the treadmill for 5 minutes before testing. A modified incremental protocol[31] was used to reach VO_2max, with subjects running at a constant speed and a 2.5% increase in grade at the end of each 3-minute stage. The subjects' speed was determined as 70% of the mile pace from their 2-mile run time during the APFT. Subject termination was determined by volitional fatigue. Maximal VO_2 is reliable and highly predictive for evaluating differences in aerobic fitness across populations[6] and was reported normalized to body weight (mL/kg/min).

Army Physical Fitness Testing

The APFT was conducted by the individual military units on a separate occasion. Push-up and sit-up tests were performed according to the Army standard protocol,[32] which records the maximal number of repetitions completed in each 2-minute timed period. Push-ups and sit-ups are widely accepted as valid indicators of muscle strength and endurance.[7]

A 2-mile run timed test was conducted and the amount of time needed to run the distance of 2 miles was recorded.[32] Distance runs are highly correlated with aerobic capacity.[6,7,33]

Musculoskeletal Assessment

Bilateral isokinetic strength of the knee (flexion/extension) and shoulder (internal/external rotation) was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Shirley, New York; see Figure 4). The reliability of isokinetic strength testing had been established in our laboratory (ICC = 0.73–0.97) for peak torque/body weight.

Isokinetic knee extension and flexion dynamometry are highly reliable (ICC = 0.96–0.97 and ICC = 0.93–0.98, respectively)[34–37] and valid[36,38,39] measures of quadriceps and hamstring muscle performance that identify military personnel at risk for overuse knee joint injury,[40–44] and significantly predict hopping, leaping, and jumping ability ($r = 0.62$–0.92, $p < 0.05$ for extension and $r = 0.65$–0.69, $p < 0.05$ for flexion)[45–47] as well as straight-line and agility sprint performance ($r = -0.42$ to -0.51, $p < 0.05$ for extension and $R > 0.55$, $p < 0.05$ for flexion).[45,48–50]

Isokinetic shoulder internal rotation and external rotation dynamometry is a highly reliable (ICC = 0.78–0.92)[51–53] and valid[36,38,39] measure of rotator cuff muscle performance, of which optimal function is considered critical in shoulder injury prevention programs.[54,55]

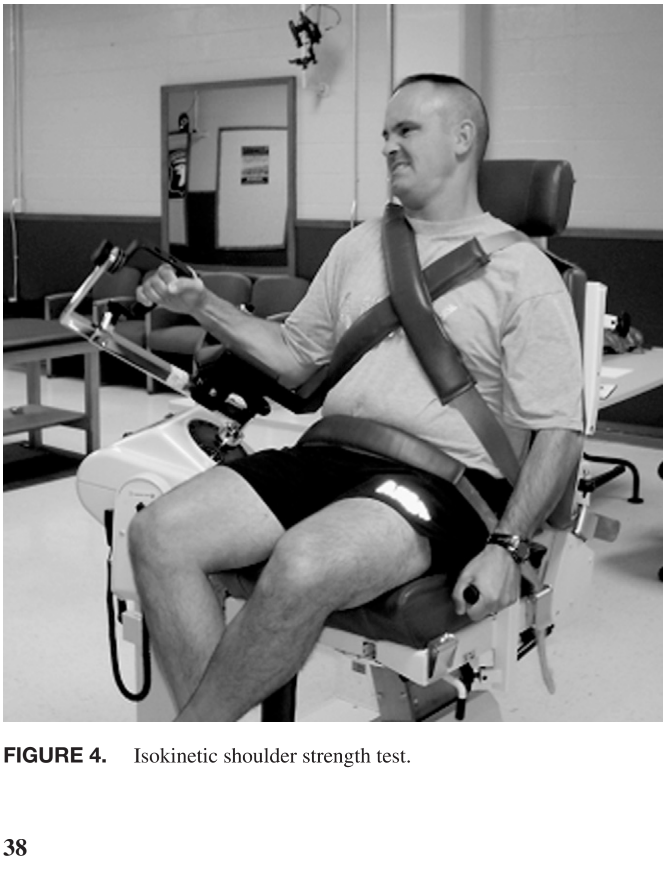

FIGURE 4. Isokinetic shoulder strength test.

To test isokinetic knee and shoulder strength, the subjects were properly fitted to the chair of the device by aligning the axis of joint rotation to the dynamometer axis. For knee strength, the subject was seated with the hip at 90°, and for shoulder strength, the subject was seated with their arm securely fitted to the dynamometer's arm at 30° of shoulder abduction. Padded straps were used to prevent extraneous movements during the test. Dynamometer range of motion stops and limb weight/gravity correction were set. The subject performed three practice trials at 50% maximal effort and three practice trials at maximal effort followed by a 60-second rest period. Peak isokinetic torque for AKE, AKR, ASIR, and ASER was measured across five, maximal effort repetitions (concentric/concentric at 60°/second) and reported normalized to percent body weight.

Statistical Analysis

Data were examined to evaluate the assumptions of normality and homogeneity of variance. Descriptive statistics (measures of central tendency and measures of dispersion) were calculated for all variables. Because the assumption of normality was met for most, but not all of the variables, Mann-Whitney *U* tests and calculation of the Spearman correlation coefficient were performed. The results of the nonparametric test agreed with the results of the corresponding parametric test (independent samples *t*-test and Pearson correlation coefficient) with respect to significance of the results (Table II). Though both parametric statistics for normally distributed data and nonparametric statistics are presented in Tables I and II, parametric statistics are reported in the text for all variables (mean ± SD). In post hoc analysis, there was one case (ASIR relative to FFM between groups) when the nonparametric and parametric tests disagreed; in this case, both statistics are presented as this also was a variable that did not meet the assumptions of normality.

For variables where the assumption of homogeneity of variance for the two-sample *t*-test for independent samples was not met, the *t*-test for unequal variances (Satterthwaite approximation) was used. Statistical significance was set at 0.05 (two-sided) a priori.

The performance variables included three distinct families—aerobic/anaerobic capacity (PNAP, MNAP, and VO_2max), APFT (push-ups, sit-ups, and run), and muscular strength variables (ASIR, ASER, AKF, and AKE). The Bonferroni procedure was applied within each family of performance variables to correct for the multiple comparisons.

Effect size for the performance variables was calculated using the absolute difference between means and the pooled SD. Statistical analysis was done using SPSS 17.0 (SPSS, Chicago, Illinois.).

RESULTS

Table I lists the demographic and anthropometric data for all subjects. Significant differences were found between group 1: ≤18%

TABLE I. Demographic and Anthropometric Data of Group 1: ≤18% BF and Group 2: >18% BF

	Group 1 (≤18% BF)						Group 2 (>18% BF)							
	n	Median	1st Q	3rd Q	Mean	SD	*n*	Median	1st Q	3rd Q	Mean	SD	Mann Whitney *U*	*T*-test
Age (Y)	44	25.5	22.0	29.0	26.6	6.1	55	30.0	24.0	38.0	30.6	7.2	0.005*	0.004*
Height (in)	44	69.5	68.0	72.0	69.6	3.4	55	70.0	68.0	71.5	69.8	2.5	0.817	0.703
Weight (lbs)	44	170.0	152.5	185.0	169.8	21.2	55	187.9	172.0	215.0	192.5	27.7	0.000*	0.000*
BMI (kg/m^2)	44	24.9	23.0	25.9	24.7	2.6	55	26.8	25.4	29.9	27.7	3.1	0.000*	0.000*
BF (%)	44	14.0	11.0	16.0	13.3	3.7	54	25.2	21.1	29.8	26.0	5.4	0.000*	0.000*
Service (Y)	42	4.5	2.8	7.6	6.0	5.2	53	8.0	3.8	14.5	9.0	6.1	0.009*	0.011*
FFM (kg)	44	66.2	60.6	72.8	66.8	8.2	54	63.3	58.4	69.6	64.6	8.0	0.186	0.177
FM (kg)	44	10.7	7.9	13.1	10.3	3.4	54	21.2	16.8	29.0	23.1	7.1	0.000*	0.000*

*Variable showed significant differences in medians and means between groups utilizing Mann Whitney *U* and *T*-test with α set a priori at $p = 0.05$.

TABLE II. Comparison of Performance Variables between Group 1: ≤18% BF and Group 2: >18% BF

	Group 1						Group 2								
	n	Median	1st Q	3rd Q	Mean	SD	*n*	Median	1st Q	3rd Q	Mean	SD	Mann Whitney *U*	*T*-test	Effect Size
PNAP (W/kg)	37	12.9	11.8	14.2	13.1	1.8	49	12.1	10.7	13.9	12.4	2.1	0.143	0.117	0.35
MNAP (W/kg)	37	8.3	7.8	8.7	8.3	0.6	49	7.3	6.7	8.0	7.2	1.0	0.000**	0.000**	1.23
VO_2max (ml/kg/min)	44	52.1	48.6	55.6	52.2	5.4	55	44.1	39.4	47.7	44.1	6.8	0.000**	0.000**	1.32
Push-Ups (2 min^{-1})	36	76.5	64.3	85.8	78.2	18.5	38	68.5	54.0	75.0	65.7	13.9	0.003**	0.002**	0.76
Sit-Ups (2 min^{-1})	36	74.5	58.0	84.5	73.6	16.2	38	70.5	61.5	82.8	73.1	14.0	0.981	0.892	0.03
Run Time (min)	36	14.8	13.2	16.8	15.2	2.3	38	15.3	13.6	16.2	15.1	2.0	0.955	0.874	0.04
ASIR (% BW)	44	62.4	53.6	75.1	66.1	16.3	54	50.0	37.9	59.3	50.4	14.5	0.000**	0.000**	1.01
ASER (% BW)	44	44.0	40.1	50.5	45.4	7.7	54	36.0	31.0	41.7	36.6	7.4	0.000**	0.000**	1.16
AKF (% BW)	44	125.9	113	146.6	127.9	23.9	54	104.0	85.1	122.6	103.6	26.6	0.000**	0.000**	0.96
AKE (% BW)	44	265.5	229.4	289.5	263.5	49	54	223.0	186.0	251.4	219	41.7	0.000**	0.000**	0.98

*Statistically significant at the 95% confidence level. **Statistically significant after application of the Bonferroni procedure within each family of performance variables. All numbers have been rounded except for *p*-values.

BF and group 2: >18% BF for body weight, BMI, % BF, age, and years of service. There were no significant differences between groups for height and FFM. Thus, the difference in body weight was due to the difference in the amount of fat mass (FM) and not FFM.

Because the correlations between both age and years of service and the fitness/performance variables were weak (absolute value < 0.3, except for the Pearson correlation coefficient [−0.314] between years of service ASER), no further adjustments were made for age or years of service in studying the association between BF and physical fitness variables.[56,57]

Subjects in group 1: ≤18% BF who met the DoD body fat goal performed significantly better than those in group 2: >18% BF on 7 of the 10 physical and physiological tests performed (Table II). Group 1: ≤18% BF had significantly higher MNAP and VO_2max than group 2: >18% BF ($p \leq 0.001$). Of the APFT, only push-ups were significantly different between groups, with Soldiers in group 1: ≤18% BF having significantly higher scores than Soldiers in group 2: >18% BF ($p = 0.002$). Group 1: ≤18% BF performed significantly better on all measures of isokinetic strength, including AKE, AKF, ASIR, and ASER ($p < 0.001$).

A post hoc analysis was performed to calculate absolute isokinetic strength and isokinetic strength normalized to FFM. Absolute strength values were significantly higher in group 1: ≤18% BF than group 2: >18% BF for ASIR (51.09 ± 14.47 vs. 43.88 ± 13.67, $p = 0.013$) and ASER (34.96 ± 7.19 vs. 31.90 ± 7.29 N*m, $p = 0.040$), and while not statistically significant, group 1: ≤18% BF had higher absolute AKE (203.52 ± 46.76 vs. 190.51 ± 41.02 N*m, $p = 0.146$) and AKF strength (98.96 ± 23.71 vs. 89.98 ± 24.23 N*m, $p = 0.069$).When isokinetic strength was normalized to FFM, there were no significant differences between group 1: ≤18% BF and group 2: >18% BF for ASIR (52.4 ± 8.6 vs. 49.4 ± 9.1% FFM, $p = 0.102$), AKE (304.1 ± 55.5 vs. 296.0 ± 54.7% FFM, $p = 0.475$), and AKF (147.6 ± 27.5 vs. 139.6 ± 33.1% FFM, $p = 0.202$). Isokinetic ASIR relative to FFM was higher in group 1: ≤18% BF (76.2 ± 18.4 vs. 67.9 ± 18.1% FFM, *t*-test $p = 0.026$, Mann-Whitney U $p = 0.054$).

DISCUSSION

In recent years, the Army has been increasingly concerned with the rise in body weight/fat and its effect on physical fitness, battlefield performance, and military appearance. Results from this study suggest that in Soldiers with similar amounts of FFM, those with less body fat and thus weight performed better on tests of anaerobic and aerobic capacity, push-ups, and isokinetic knee and shoulder strength. In general, this study substantiates, if the excess body weight is from higher body fat mass, overall physical fitness is compromised.

Since excess body fat is noncontractile, does not assist in force generation, increases the force requirements of muscles, weighs the body down during acceleration, and requires more energy to move the heavier mass through space, it is not surprising that it has a negative impact on aerobic performance.[58,59] In this study, group 1: ≤18% BF performed significantly better on the VO$_2$max test than group 2: >18% BF. In addition, the correlation between % BF and VO$_2$max was strong ($r = -0.633$, $p < 0.001$), a finding consistent with studies reporting a negative relationship between aerobic capacity and % BF.[4,60] This relationship corresponds to the physiological condition where the capacity for body propulsion is decreased as % BF, or nonenergy-producing tissue, increases.[59] Figure 5 shows that there is some variability in the relationship between % BF and the VO$_2$max, but in general, aerobic capacity improves with a reduction in % BF.

Sharp et al.[6] reported no significant change in VO$_2$max in a cohort of Army Soldiers tested at two time periods, 1978 and 1998 (VO$_2$max 50.7 ± 4.8 and 50.6 ± 6.2, respectively), despite a significant increase in body fat (16.2 ± 5.3% and 18.7 ± 4.8%, $p < 0.05$).[6] The increase in body fat from 16.2% to 18.8%, although statistically significant, is a range of body fat that is below the most stringent maximal allowable body fat level for Army personnel. From our data, as % BF increases above approximately the 15% threshold, there is a more dramatic decrease in aerobic capacity (see Figure 5).

Maximal oxygen uptake and 2-mile run times have been reported to be highly correlated ($r = -0.76$ to -0.91).[5,6,61–63] In the present study, there was a very weak nonsignificant association between 2-mile run time and VO$_2$max. It is unknown whether subjects performed the APFT at maximal effort during testing or whether they merely performed each task to pass the Army standard requirements. Other researchers have also raised questions regarding the extent to which a Soldier performs maximally vs. achieving the minimal scores needed to pass the AFPT.[6,64] The weak association would substantiate the notion that Soldiers did not perform at maximal effort on the 2-mile run test. This limitation may in part explain why Soldiers in group 1: ≤18% BF did not perform significantly better than Soldiers in group 2: >18% BF on the sit-up and the 2-mile timed run tests.

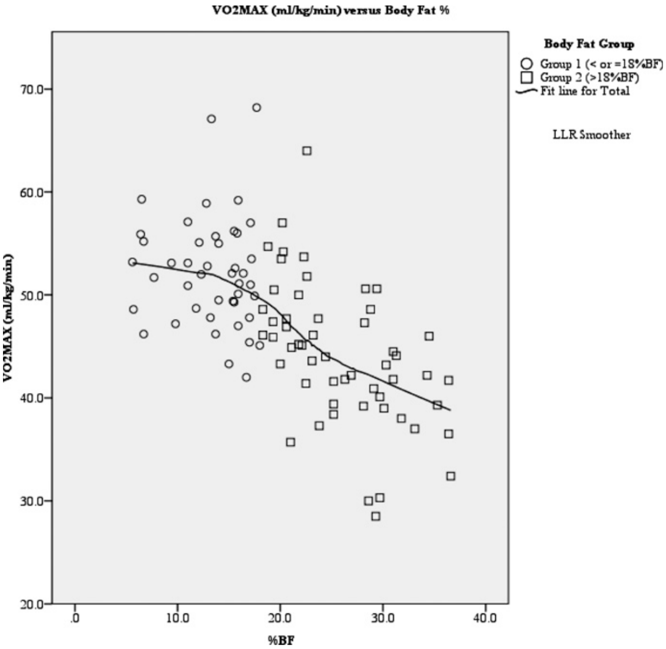

FIGURE 5. Maximal oxygen uptake plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

Limited previous research has evaluated the impact of body composition on anaerobic power and anaerobic capacity. A study examining the relationship between muscle fiber type, body composition, and anaerobic power utilizing a cycle ergometer test found that the morphological variables that had the highest positive correlation to maximal power output were total body mass and fat free mass ($r = 0.54$ and 0.57, respectively).[65] These results may help to explain why there was no significant difference between groups for anaerobic power in our study. Since our results showed that anaerobic capacity was significantly better in group 1: ≤18% BF, this suggests that leaner Soldiers perform better in anaerobic tasks lasting for a longer duration. Figure 6 shows that in general, there is a decrease in anaerobic capacity as % BF increases, with a sharper decline in performance above approximately the 20% body fat level.

Not only is excess body fat negatively associated with aerobic and anaerobic capacity; it has been negatively correlated with measures of strength that use the body as the principal resistance (push-ups, vertical jump) as well as those that do not (isokinetic tests, 1-repetition max).[7,8] Results of the strength testing in this study are in agreement with these findings, in which push-ups and isokinetic AKE, AKF, ASIR, and ASER were significantly, negatively correlated to % BF.

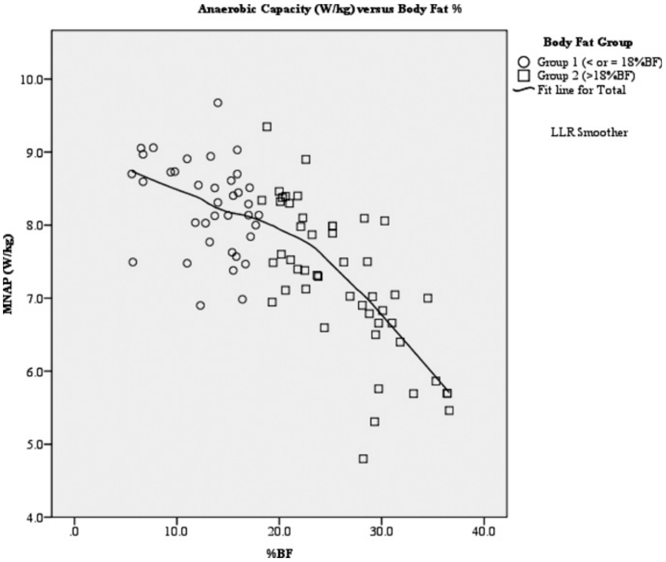

FIGURE 6. Anaerobic capacity plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

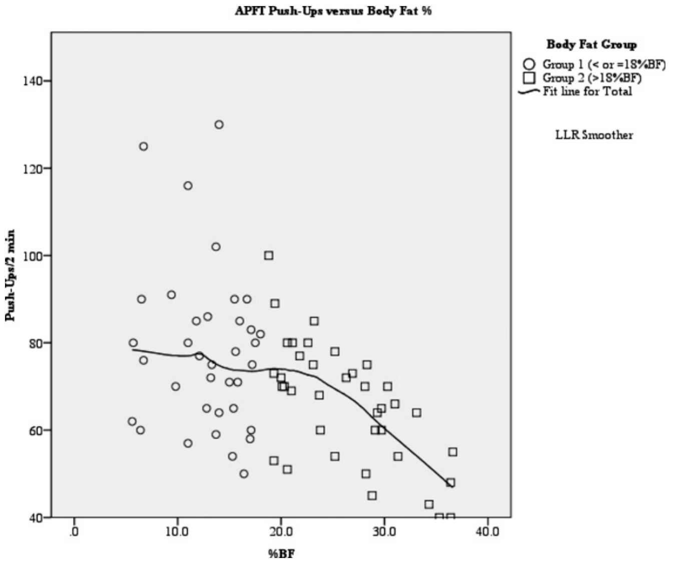

FIGURE 7. APFT push-up score plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

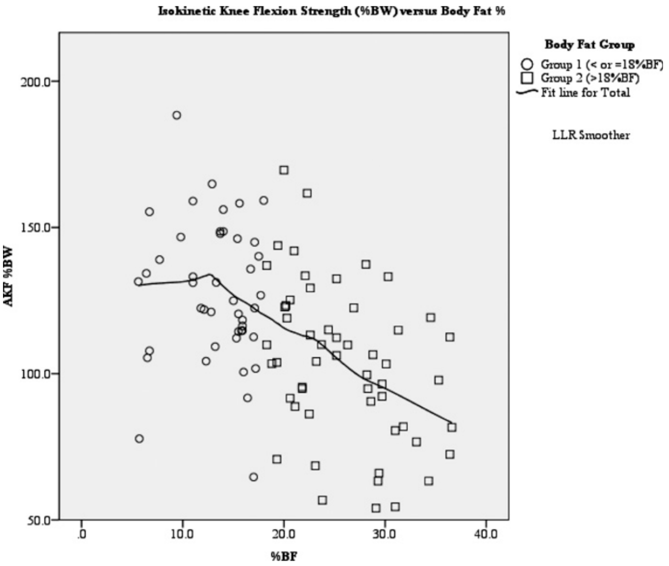

FIGURE 8. Isokinetic knee flexion strength plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

Sit-ups, however, were poorly correlated to % BF. The scatter plot in Figure 7 shows that there is more variability in the relationship between % BF and push-up performance in the lower body fat range; however, above the 20% body fat level, there is a more dramatic decrease in number of push-ups performed.

In a study examining the association between body composition and physical fitness, 140 Army recruits completed strength testing including standing long jump distance; number of sit-ups, push-ups, and pull-ups; back extension; and a 2-mile run.[8] Researchers concluded % BF was the strongest predictor of muscle strength and running performance and that the amount of muscle mass was not related to muscle strength. Although it is generally accepted that as body mass increases, both FFM and strength increase, muscle strength does not proportionately increase with total body mass.[7] There is a point at which the power produced by the higher amount of FFM is not enough to offset the additional body weight and the resistance created increases the energy requirement to perform the work.[9] This may in part explain why Soldiers in our study with less body fat and body weight but similar amounts of FFM (Table II), performed better on the majority of physical fitness tests. Figure 8 depicts the relationship between AKF and % BF, which shows some individual variability, but in general, as % BF increases, knee flexion strength decreases, with a sharper decline at approximately the 15% BF level.

In examining the impact that FFM had on physical performance, Pearson correlation coefficients for FFM and 10 physical fitness tests revealed a very weak, nonsignificant (r = 0.002–0.164) relationship. Further, when the isokinetic strength tests were normalized to FFM, there were no significant differences between groups except for ASIR, which trended higher for group 1: ≤18% BF. When normalized to total body mass, each measure of isokinetic strength was significantly higher in group 1: ≤18% BF, suggesting that the contribution of fat mass to total body mass accounted for the relative decrease in performance. The results of this study reinforce previous research showing that despite possessing similar levels of absolute FFM, individuals with less % BF possess greater levels of aerobic capacity and strength.[8,10,14,66]

The relationship between FFM and muscle strength and endurance is stronger in tests that involve carrying a load and lifting.[9,67] Vogel et al.[59] reported that absolute lifting capacity is directly related to FFM and not related to % BF in men.[59] However, since % BF in contemporary Soldiers is higher, there may be a point in which this higher amount of fat will also negatively impact absolute lifting capacity. Although our strength tests did not directly measure load carriage ability or overhead lifting, the absolute peak isokinetic strength values for ASIR and ASER were significantly greater in group 1: ≤ 18% BF, and while not significant, AKE and AKF showed similar trends. This suggests that in our population, the leaner subjects were able to produce greater absolute strength despite having significantly less total mass. Future studies may benefit from including loaded carry and maximal lifting tests to evaluate whether higher body weight provides a performance benefit or detriment and how that affects the other areas of physical fitness and military performance.

Currently, there is debate over the concept of “large and in charge” body size and how it impacts overall physical fitness and military performance. Critics of the current body weight and fat standards argue that heavier Soldiers perform better on a variety of military tasks such as lifting, pushing, and carrying external loads and that these job tasks are required with greater frequency in specific military occupational specialties (MOS). Although a higher body weight may provide some benefit to certain military tasks, carrying excess weight, as fat, is associated with poor physical fitness. One of the missions of military training is to improve physical fitness as it is generally accepted that this will increase the likelihood of success in battle.[68,69] Blount et al.[68] reported that a Soldier who is more physically fit can cover a longer distance in a shorter time than someone who is less fit, reducing time in the enemy's line of fire. Excess body fat may have a negative impact on important battlefield requirements including low and high crawl speed and endurance and climbing various terrains for long distances.[68] As the % BF of today's Soldiers continues to rise, research is warranted to determine body fat levels that are optimal for maximizing a wide range of physical fitness parameters and indicators of combat readiness, and further, the impact of losing excess fat on improving military fitness and performance.

The outcomes of this study present practical applications to the military population not only in improving a Soldier's physical fitness and thus military readiness, but helping to reduce a Soldier's risk of injury. Knapik et al.[70] reported that Soldiers with lower aerobic fitness and muscle strength had a higher occurrence of musculoskeletal injuries. Essentially, individuals with excess % BF may possess physiological fitness and musculoskeletal strength deficits, reduced military readiness, and increased risk for unnecessary injury.

CONCLUSIONS

As the body weight/fat of military personnel continues to rise, it is important to identify the impact it has on military training and combat. It is important for the military to employ techniques that provide more direct measures of body fat and FFM to accurately identify Soldiers with excess weight from body fat. This study provides supportive evidence that if the increase in body weight is due to excess body fat, physical fitness is compromised, which ultimately affects military preparedness. Future research is warranted to examine the direct relationship between body composition and physical readiness, which is more specific to a Soldier's MOS, tactical activities, and combat effectiveness.

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REFERENCES

1. U.S. Department of the Army: The Army weight control program, Army regulation 600-9. Washington, DC, Dept. of the Army, 2006.
2. Flegal K, Carroll M, Ogden C, Curtin L: Prevalence and trends in obesity among US adults, 1999–2008. JAMA 2010; 303(3): 235–41.
3. Christeson W, Taggart A, Messner-Zidell S: Too fat to fight, pp 1–16. Washington, DC, Mission: Readiness, 2010. Available at http://www.clarionledger.com/assets/pdf/D0156173422.PDF; accessed May 12, 2010.
4. Friedl K: Can you be large and not obese? The distinction between body weight, body fat and abdominal fat in occupational standards. Diabetes Technol Ther 2004; 6(5): 732–49.
5. Harmon E, Sharp R, Manikowski P, Frykman P, Rosenstein R: Analysis of a muscle strength database. J Appl Sports Sci Res 1988; 2(3): 54.
6. Sharp M, Patton J, Knapik J, et al: Comparison of the physical fitness of men and women entering the U.S. Army: 1978–1998. Med Sci Sports Exerc 2001; 34(2): 356–63.
7. Vanderburgh P, Crowder T: Body mass penalties in the physical fitness tests of the Army, Air Force, and Navy. Mil Med 2006; 171(8): 753–6.
8. Mattila V, Kaj T, Marttinen M, Pihlajamaki H: Body composition by DEXA and its association with physical fitness in 140 conscripts. Med Sci Sports Exerc 2007; 39(12): 2242.
9. Harman E, Frykman P: The relationship of body size and composition to the performance of physically demanding military tasks. Body composition and physical performance, pp 105–118. Washington, DC, National Academies Press, 1992.
10. Bohnker B, Sack D, Wedierhold L, Malakooti M: Navy physical readiness test scores and body mass index (spring 2002 cycle). Mil Med 2005; 170(10): 851–4.
11. Jonnalagadda S, Skinner R, Moore L: Overweight athlete: fact or fiction? Curr Sports Med Rep 2004; 3: 198–205.
12. Niebuhr D, Scott C, Li Y, Bedno S, Han W, Powers T: Preaccession fitness and body composition as predictors of attrition in U.S. Army recruits. Mil Med 2009; 174(7): 695–701.
13. Kusano M, Vanderburgh P, Bishop P: Impact of body size on women's military obstacle course performance. Biomed Sci Instrum 1997; 34: 357–62.
14. Knapik J, Sharp M, Darakjy S, Jones S, Hauret K, Jones B: Temporal changes in the physical fitness of US Army recruits. Sports Med 2006; 36(7): 613.
15. Armed Forces Health Surveillance Center: Diagnoses of overweight/obesity, active component, U.S. Armed Forces, 1998–2008. MSMR 2009; 16(01): 2–7.
16. Rinke W, Herzberger J, Erdtmann F: The Army Weight Control Program: a comprehensive mandated approach to weight control. J Am Diet Assoc 1985; 85(11): 1429–36.
17. U.S. Department of the Army: Combat Skills of the Soldier: Field Manual 21–75. Washington, DC, Dept. of the Army, 1984.
18. U.S. Department of the Army: The Warrior Ethos and Soldier Combat Skills: Field Manual 3–21. Washington, DC, Dept. of the Army, 2008.
19. Ballard T, Fafara L, Vukovich M: Comparison of Bod Pod (R) and DXA in female collegiate athletes. Med Sci Sports Exerc 2004; 36(4): 731.
20. Fields D, Goran M, McCrory M: Body-composition assessment via air-displacement plethysmography in adults and children: a review. Am J Clin Nutr 2002; 75(3): 453.
21. Malavolti M, Battistini N, Dugoni M, Bagni B, Bagni I, Pietrobelli A: Effect of intense military training on body composition. J Strength Cond Res 2008; 22(2): 503.
22. Noreen E, Lemon P: Reliability of air displacement plethysmography in a large, heterogeneous sample. Med Sci Sports Exerc 2006; 38(8): 1505.
23. Vescovi J, Zimmerman S, Miller W, Hildebrandt L, Hammer R, Fernhall B: Evaluation of the BOD POD for estimating percentage body fat in a heterogeneous group of adult humans. Eur J Appl Physiol 2001; 85(3): 326–32.
24. Weyers A, Mazzetti S, Love D, Gomez A, Kraemer W, Volek J: Comparison of methods for assessing body composition changes during weight loss. Med Sci Sports Exerc 2002; 34(3): 497.
25. Siri WE: Body composition from fluid spaces and density: analysis of methods. In: Techniques for Measuring Body Composition, pp 223–224. Edited by Brozek J, Henchel A. Washington, DC, Natl Acad Sciences/Natl Res Council, 1961.
26. Smith J, Hill D: Contribution of energy systems during a Wingate power test. Br J Sports Med 1991; 25(4): 196.
27. Bar-Or O: The Wingate anaerobic test: an update on methodology, reliability and validity. Sports Med 1987; 4(6): 381–94.
28. Zagatto A, Beck W, Gobatto C: Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. J Strength Cond Res 2009; 23(6): 1820.
29. Del Coso J, Mora-Rodríguez R: Validity of cycling peak power as measured by a short-sprint test versus the Wingate anaerobic test. Appl Physiol Nutr Metab 2006; 31(3): 186.
30. Attinger A, Tuller C, Souren T, Tamm M, Schindler C, Brutsche M: Feasibility of mobile cardiopulmonary exercise testing. Swiss Med Wkly 2006; 136(1–2): 13–8.

31. Kang J, Chaloupka E, Mastrangelo M, Biren G, Robertson R: Physiological comparisons among three maximal treadmill exercise protocols in trained and untrained individuals. Eur J Appl Physiol 2001; 84(4): 291–5.
32. Williamson D, Bathalon G, Sigrist L, et al: Military services fitness database: development of a computerized physical fitness and weight management database for the U.S. Army. Mil Med 2009; 174(1): 1–8.
33. Knapik J, Cuthie J, Canham M: Injury incidence, injury risk factors, and physical fitness of US Army basic trainees at Fort Jackson, SC. Technical Report 29-HE-7513-98. Aberdeen Proving Ground, MD, U.S. Army Center for Health Promotion and Preventive Medicine, 1998.
34. Keskula D, Dowling J, Davis V, Finley P, Dell'Omo D: Interrater reliability of isokinetic measures of knee flexion and extension. J Athl Train 1995; 30(2): 167.
35. McCleary R, Andersen J: Test-retest reliability of reciprocal isokinetic knee extension and flexion peak torque measurements. J Athl Train 1992; 27(4): 362.
36. Drouin J, Valovich-mcLeod T, Shultz S, Gansneder B, Perrin D: Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. Eur J Appl Physiol 2004; 91(1): 22–9.
37. Sole G, Hamrén J, Milosavljevic S, Nicholson H, Sullivan S: Test-retest reliability of isokinetic knee extension and flexion. Arch Phys Med Rehabil 2007; 88(5): 626–31.
38. Brown L: Isokinetics in Human Performance, pp 247–8. Champaign, IL, Human Kinetics, 2000.
39. Perrin D: Isokinetic Exercise and Assessment pp 75–87, 121–9. Champaign, IL, Human Kinetics, 1993.
40. Duvigneaud N, Bernard E, Stevens V, Witvrouw E, Van Tiggelen D: Isokinetic assessment of patellofemoral pain syndrome: a prospective study in female recruits. Isokinet Exerc Sci 2008; 16(4): 213–9.
41. Van Tiggelena D, Witvrouwb E, Coorevitsb P, Croisierc J, Rogetd P: Analysis of isokinetic parameters in the development of anterior knee pain syndrome: a prospective study in a military setting. Isokinet Exerc Sci 2004; 12(4): 223–8.
42. Myer G, Ford K, Barber Foss K, Liu C, Nick T, Hewett T: The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. Clin J Sport Med 2009; 19(1): 3.
43. Orchard J, Marsden J, Lord S, Garlick D: Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. Am J Sports Med 1997; 25(1): 81.
44. Yeung S, Suen A, Yeung E: A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. Br J Sports Med 2009; 43(8): 589–94.
45. Kovaleski J, Heitman R, Andrew D, Gurchiek L, Pearsall A: Relationship between closed-linear-kinetic-and open-kinetic-chain isokinetic strength and lower extremity functional performance. J Sport Rehabil 2001; 10(3): 196–204.
46. Pincivero D, Lephart S, Karunakara R: Relation between open and closed kinematic chain assessment of knee strength and functional performance. Clin J Sport Med 1997; 7(1): 11.
47. Shaffer S, Payne E, Gabbard L, Garber M, Halle J: Relationship between isokinetic and functional tests of the quadriceps. Platform presentation, 1994 APTA Combined Sections Meeting, New Orleans, LA. J Orthop Sports Phys Ther 1994; 19(1): 55.
48. Lephart S, Perrin D, Fu F, Gieck J, McCue F, Irrgang J: Relationship between selected physical characteristics and functional capacity in the anterior cruciate ligament-insufficient athlete. J Orthop Sports Phys Ther 1992; 16(4): 174.
49. Negrete R, Brophy J: The relationship between isokinetic open and closed chain lower extremity strength and functional performance. J Sport Rehabil 2000; 9(1): 46–61.
50. Anderson M, Gieck J, Perrin D, Weltman A, Rutt R, Denegar C: The relationships among isometric, isotonic, and isokinetic concentric and eccentric quadriceps and hamstring force and three components of athletic performance. J Orthop Sports Phys Ther 1991; 14(3): 114.
51. van Meeteren J, Roebroeck M, Stam H: Test-retest reliability in isokinetic muscle strength measurements of the shoulder. J Rehabil Med 2002; 34(2): 91–5.
52. Sell T, Tsai Y, Smoliga J, Myers J, Lephart S: Strength, flexibility, and balance characteristics of highly proficient golfers. J Strength Cond Res 2007; 21(4): 1166.
53. Mandalidis D, Donne B, O'Regan M, O'Brien M: Reliability of isokinetic internal and external rotation of the shoulder in the scapular plane. Isokinet Exerc Sci 2001; 9(1): 65–72.
54. Ellenbecker T, Cools A: Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. BMJ 2010; 44(5): 319.
55. Ellenbecker T, Davies G: The application of isokinetics in testing and rehabilitation of the shoulder complex. J Athl Train 2000; 35(3): 338.
56. Elashoff J: Analysis of covariance: a delicate instrument. Am Educ Res J 1969; 6(3): 383.
57. Porter A, Raudenbush S: Analysis of covariance: its model and use in psychological research. J Couns Psychol 1987; 34(4): 383–92.
58. Boileau R, Lohman T: The measurement of human physique and its effect on physical performance. Orthop Clin North Am 1977; 8(3): 563–81.
59. Vogel JA, Friedl KE: Army data: body composition and physical capacity. In: Body Composition and Physical Performance Applications for Military Services. Edited by Marriot BM, Grunstup-Scott J. Washington, DC, National Academies Press, 1992.
60. Cureton K, Sparling P: Distance running performance and metabolic responses to running in men and women with excess weight experimentally equated. Med Sci Sports Exerc 1980; 12(4): 288–94.
61. Mello R, Murphy M, Vogel J: Relationship between the Army two mile run test and maximal oxygen uptake. Natick, MA, Army Research Institute of Environmental Medicine, 1984.
62. Fitzgerald P, Vogel JA, Daniels W, et al. The Body Composition Project: A Summary Report and Descriptive Data. Natick, MA, U.S. Army Research Institute of Environmental Medicine, 1986.
63. Knapik J: The Army Physical Fitness Test (APFT): a review of the literature. Mil Med 1989; 154(6): 326.
64. O'Connor J, Bahrke M, Tetu R: Active Army physical fitness survey. Mil Med 1988; 155(12): 579–85.
65. Patton J, Kraemer W, Knuttgen H, Harman E: Factors in maximal power production and in exercise endurance relative to maximal power. Eur J Appl Physiol Occup Physiol 1990; 60(3): 222–7.
66. Franchini E, Nunes A, Moraes J, Del Vecchio F: Physical fitness and anthropometrical profile of the Brazilian male judo team. J Physiol Anthropol 2007; 26(2): 59–67.
67. Mello R, Murphy M, Vogel JA: Relationship between a two mile run for time and maximal oxygen uptake. J Appl Sport Sci Res 1988; 2(1): 9–12.
68. Blount E, Tolk A, Ringleb S: Physical Fitness for Tactical Success. Manuscript preparation for Virginia Modeling, Analysis and Simulation Center (VMASC) Capstone Conference, Old Dominion University, Norfolk, VA 2010.
69. Knapik J, Darakjy S, Scott S, et al: Evaluation of a standardized physical training program for basic combat training. J Strength Cond Res 2005; 19(2): 246–53.
70. Knapik J, Ang P, Reynolds K, Jones B: Physical fitness, age, and injury incidence in infantry soldiers. J Occup Environ Med 1993; 35(6): 598.