Effect of resistance training on women's strength/power and occupational performances

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Laboratory for Sports Medicine/Center for Sports Medicine, The Pennsylvania State University, University Park, PA 16802; The Human Performance Laboratory, Ball State University, Muncie, IN 47306; Military Performance Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760; Neuromuscular Research Center, Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, FINLAND; and Department of Sport Sciences, Colorado College, Colorado Springs, CO 80903

ABSTRACT

KRAEMER, W. J., S. A. MAZZETTI, B. C. NINDL, L. A. GOTSHALK, J. S. VOLEK, J. A. BUSH, J. O. MARX, K. DOHI, A. L. GÓMEZ, M. MILES, S. J. FLECK, R. U. NEWTON, and K. HÄKKINEN. Effect of resistance training on women's strength/power and occupational performances. *Med. Sci. Sports Exerc.*, Vol. 33, No. 6, 2001, pp. 1011–1025. **Purpose:** The effects of resistance training programs on strength, power, and military occupational task performances in women were examined. **Methods:** Untrained women aged (mean ± SD) 23 ± 4 yr were matched and randomly placed in total- (TP, $N = 17$ and TH, $N = 18$) or upper-body resistance training (UP, $N = 18$ and UH, $N = 15$), field (FLD, $N = 14$), or aerobic training groups (AER, $N = 11$). Two periodized resistance training programs (with supplemental aerobic training) emphasized explosive exercise movements using 3- to 8-RM training loads (TP, UP), whereas the other two emphasized slower exercise movements using 8- to 12-RM loads (TH, UH). The FLD group performed plyometric and partner exercises. Subjects were tested for body composition, strength, power, endurance, maximal and repetitive box lift, 2-mile loaded run, and U.S. Army Physical Fitness Tests before (T0) and after 3 (T3) and 6 months of training (T6). For comparison, untrained men ($N = 100$) (MEN) were tested once. **Results:** Specific training programs resulted in significant increases in body mass (TP), 1-RM squat (TP, TH, FLD), bench press (all except AER), high pull (TP), squat jump (TP, TH, FLD), bench throw (all except AER), squat endurance (all except AER), 1-RM box lift (all except aerobic), repetitive box lift (all), push-ups (all except AER), sit-ups (all except AER), and 2-mile run (all). **Conclusions:** Strength training improved physical performances of women over 6 months and adaptations in strength, power, and endurance were specific to the subtle differences (e.g., exercise choice and speeds of exercise movement) in the resistance training programs (strength/power vs strength/hypertrophy). Upper- and total-body resistance training resulted in similar improvements in occupational task performances, especially in tasks that involved upper-body musculature. Finally, gender differences in physical performance measures were reduced after resistance training in women, which underscores the importance of such training for physically demanding occupations. **Key Words:** WOMEN'S HEALTH, FITNESS, GENDER DIFFERENCES, MANUAL MATERIALS HANDLING, MILITARY

Over the past 20 years, there has been an increase in the number of women performing physically demanding occupational jobs (military, police, firefighters, industrial, etc.). More specifically, in the U.S. Army, the prevalence of women engaged in physically demanding military occupational specialties (MOSs) continues to increase. Such physically demanding, heavy MOSs require muscular strength and long-term load bearing capabilities of up to 40 kg (29). Therefore, improving our understanding of the potential interventions (e.g., resistance training) available to optimize women's performance in physically demanding jobs appears to be an important perspective in the work place.

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It is well known that a variety of resistance training programs can stimulate an increase in one-repetition maximum (1-RM) strength in women (5,8,32,33,37,38). However, only few studies have attempted to make direct comparisons of different styles of resistance training programs to determine adaptational differences. With short-term training, Marcinik et al. (22) compared high intensity (i.e., 70% of 1-RM) versus low intensity (i.e., 40% of 1-RM) aerobic/circuit resistance training in women who were U.S. Naval recruits. After 8 wk, 1-RM bench press performance was significantly greater in the high-intensity group, whereas no difference was observed between groups in 1-RM leg press performances. In a long-term training study (i.e., 5 months), Calder et al. (4), reported no differences in women's lower- and upper-body 1-RM strength and body composition between whole-body and split-body part resistance training routines (i.e., exercise the whole-body or only certain muscle groups during each workout). The lack of differences in these studies may be attributed to limited training time for differential adaptations to be realized and/or a high degree of carry over from the training programs to the dependent variables (9). Nevertheless, long-term studies that will help delineate which styles of resistance training optimize strength performance in women are evidently needed.

To our knowledge, only one investigation has examined the influence of strength performance improvements after resistance training on occupational task capabilities in women (15). Knapik (15) trained 13 U.S. Army women soldiers using progressive resistance exercise 3 $d \cdot wk^{-1}$ for 14 wk. The training significantly improved maximal box lift and 10-min repetitive box lift performances. Despite these substantial improvements, this study did not include a control group of U.S. Army men of similar age. Because most military tasks were designed according to the physical ability of an average man, gender comparisons of such data may permit a better evaluation of the extent and type of physical training needed in women. Furthermore, one might argue that long-term resistance training in women would reduce gender differences in physical performance measures observed pretraining.

Gender comparisons of strength performance have been examined in detail, and it has been observed that compared with men, women's upper-body strength (55% of men) is less than that of their lower-body strength (72% of men) (3,14,20,29,38). Although only few studies have examined the influence of upper-body resistance training on military occupational task performance, it has been suggested that upper-body strength played an important role in load carriage (17). Furthermore, upper-body resistance training does not affect muscle fiber adaptations or 1-RM strength performance in lower-body musculature (19). The obvious contribution of the upper-body to various physical performance tasks would be highly related to the type of task performed and its inherent characteristics (i.e., dependence on upper-body musculature). To date, no data are available to address this question in women. Therefore, the primary purpose of this investigation was to examine the influence of different periodized resistance training programs on strength, power, endurance, and military occupational task performances in women over a 6-month training period. In addition, we wanted to partial out the role of upper-body contributions to various physical performance tasks. A secondary purpose was to examine the physical performance characteristics of women in comparison with a typical active, but nonresistance-trained, group of men to help us better understand gender differences before and after various resistance training programs.

METHODS

Experimental design and approach to the problem. A research design using different styles of resistance training programs (i.e., choice of exercise, intensity, volume of exercise, and velocity of movement) was used to partial out differential training adaptations in physical performances. Included in this design were distinct groups that trained with only the upper-body musculature. A wide array of experimental tests was administered, which had contextual relevance to strength, power, muscular endurance, aerobic performance, and occupational tasks. In addition, a normative group of men were tested to assess the efficacy of specific training programs in abating gender differences in muscle and occupational performances.

Subjects were tested and then subsequently matched for body size and strength. Then they were randomly assigned to one of six training groups. The training groups included total strength/power resistance (TP) ($N = 17$), total strength/hypertrophy resistance (TH) ($N = 18$), upper strength/power resistance (UP) ($N = 18$), upper strength/hypertrophy resistance (UH) ($N = 15$), field ballistic plyometric and partner-resisted exercise (FLD) ($N = 14$), and aerobic training (AER) ($N = 11$) groups. Subjects were tested pretraining (T0) and again after 3 months (T3) and 6 months (T6) of training. At each data collection session, body mass, fat-free mass, percent body fat, 1-RM squat, 1-RM bench press, 1-RM high pull, squat jump power, bench press throw power, squat endurance, 1-RM box lift, repetitive box lift, 2-mile loaded run, and U.S. Army Physical Fitness Test variables (i.e., push-ups, sit-ups, and 2-mile run) were assessed. All women then participated in their respective 24-wk exercise training programs including supplemental aerobic exercise 3 $d \cdot wk^{-1}$.

Subjects. All women and men were informed of the potential risks associated with this investigation and signed an informed consent document approved by the university Institutional Review Board and by the Human Use Review Office of the Army Surgeon General, Washington, DC. Women were medically screened by a physician before the study for inclusion. None of the subjects had any confounding orthopedic, endocrine, or other disorders that would contraindicate participation in a heavy-resistance training program. All women also tested negative on a pregnancy test before the start of the study. No significant ($P \leq 0.05$) differences were observed among women's groups in any variables before (T0) training (see Table 1).

EXPERIMENTAL PROTOCOLS

Each experimental test used in this investigation had a test-retest reliability correlation (Intraclass Rs) of $R \geq 0.95$. This was an important factor in carefully documenting the changes due to training. All subjects were carefully familiarized with all testing protocols and procedures to eliminate acute learning effects that would inflate resulting training-induced values (7). When appropriate, similar verbal encouragement was provided to help each subject attain a maximal performance in the test. In addition, proper spotting was used for all tests to ensure the safety of each subject.

Anthropometry and Body Composition

Height and weight were determined using a standard, calibrated physician's scale. Skin-fold thicknesses were obtained at seven sites with a Lange skin-fold caliper at the

TABLE 1. Subject characteristics by group before the start of the study.

Group	Age (yr)	Height (cm)	BM (kg)	% Fat	1-RM Sq (kg)	1-RM Bp (kg)
TP (N = 17)	22.4 ± 3.5	163.7 ± 7.5	64.1 ± 8.8	25.8 ± 5.9	53.0 ± 12.3	35.4 ± 7.3
TH (N = 18)	23.8 ± 3.7	165.4 ± 5.4	63.2 ± 7.0	23.9 ± 5.0	52.4 ± 11.4	32.9 ± 9.1
UP (N = 18)	22.7 ± 4.0	165.5 ± 7.2	66.7 ± 10.7	25.5 ± 6.1	55.5 ± 11.1	34.1 ± 6.3
UH (N = 15)	23.5 ± 3.7	166.7 ± 6.2	65.7 ± 12.1	26.3 ± 5.3	51.9 ± 9.0	35.1 ± 8.0
FLD (N = 14)	22.6 ± 4.4	166.5 ± 7.8	67.7 ± 12.2	29.2 ± 5.5	44.5 ± 12.1	28.0 ± 7.6
AER (N = 11)	24.8 ± 4.3	165.7 ± 5.6	68.9 ± 10.6	30.3 ± 7.5	40.8 ± 9.5	29.9 ± 5.1
MEN (N = 100)	22.1 ± 2.7	176.9 ± 6.0†	78.7 ± 9.4†	16.5 ± 6.4†	100.6 ± 25.0†	81.0 ± 19.7†

Values are means ± SD, BM, body mass; 1-RM, one-repetition maximum; Sq, squat; Bp, bench press; TP, total strength/power; TH, total strength/hypertrophy; UP, upper strength/power; UH, upper strength/hypertrophy; FLD, field; AER, aerobic.
† $P \leq 0.05$ vs all corresponding women's values.

chest, midaxillary, triceps, subscapular, abdomen, suprailiac, and thigh after the procedures previously described by Lohman et al. (21). All skin-fold measurements were measured on the right side of the subject's body by the same trained and experienced investigator. Repeated trials were performed until two measures within 2 mm were obtained. Results were determined as the average of the two measures at each site. Respective equations (i.e., female and male) described by Jackson and Pollock (13) were used to estimate body density. Percent body fat was subsequently estimated using the value obtained for body density and the Siri equation (31), and fat-free mass was calculated by subtracting fat mass from body mass.

Strength and Power Performance Measures

Plyometric power system. All resistance exercise testing protocols were performed on separate days using the Plyometric Power System (Lismore, NSW, Australia) (39). The Plyometric Power System (PPS) consists of a Smith machine and barbell interfaced to an on-line computer system that allows the accurate determination of strength and power data. Resistance was provided by the barbell and plate-loaded weights that can only move in the vertical direction along two steel shafts attached with linear bearings to both ends of the bar. This machine permits movements such as the squat to be performed in a dynamic, ballistic manner with minimal risk to the subject. The machine was connected to a rotary encoder that recorded the position and direction of the bar with an accuracy of 0.2 mm.

One-repetition maximum tests. The testing protocol has been previously described by Kraemer et al. (18). One repetition maximum (1-RM) lifts were determined for the squat, bench press, and high pull, and testing consisted of two warm-up sets using three to five repetitions at 60% and 80% of their estimated 1-RM followed by three to five subsequent attempts to determine the 1-RM load. The highest mass lifted (kg) with proper form was used as the 1-RM test score.

Proper form in the three lifts consisted of the following criteria. With the barbell placed on the shoulders, a successful parallel squat attempt required descending by flexing the knees and hips until the proximal head of the femur reached the same horizontal plane as the superior border of the patella. The subject then returned to a standing position. For the 1-RM bench press, the subject gripped the barbell slightly wider than shoulder width and lowered the barbell under control until it lightly touched (i.e., without bouncing) the chest. The subject then lifted the barbell back to a straight-arm position while keeping the feet and hips in contact with the floor and bench. For the 1-RM high pull, the subject stood upright and gripped the barbell with a pronated overhand grip slightly wider than the shoulders. With the arms extended at the sides of the body and feet positioned so that the instep of each foot was directly under the barbell, the subject extended the hips powerfully to full extension, rose onto the toes, shrugged the shoulders, and pulled the barbell to medial clavicular height. Once the subject had begun upward acceleration of the barbell, the investigator applied the brake of the PPS. By applying the brake, the barbell was prevented from descending, but its upward movement was not interrupted for a successful attempt, the barbell must have reached the height of a standing subject's medial clavicle. The highest mass (kg) lifted in each lift was used for subsequent analyses.

Squat and bench power outputs. For the determination of power in the squat jump and bench throw, the PPS was again used after one warm-up set at 15% of their previously determined 1-RM squat value. Subjects performed three to five attempts of squat jumps using 30% of their 1-RM with 2-min rests between attempts. Thirty percent of the 1-RM was chosen because mechanical power appears to be maximized near this value (25,39). The squat jump required the subject to perform a parallel squat ballistically (i.e., upon reaching the bottom position explosively jump with the load) to produce maximum power output in the concentric phase of the lift. The break on the PPS was then used to eliminate the added load upon landing. For the bench throw power test, subjects started with the arms extended straight over the shoulders and were instructed to perform a ballistic bench press releasing the bar at the end of the concentric movement to produce the maximum power output (24). The brake on the system was employed to stop the bar above the subject. The resultant data were collected by the online computer system and power outputs were then calculated with the highest power output (W) of each lift used for analyses.

Squat endurance test. The squat endurance test required repetitive squat repetitions using proper form with an absolute load of 45.36 kg. The barbell and its movement were individually standardized for each subject to move exactly 36 cm. Subjects maintained a predetermined pace with the sound of a metronome at a rate of 37.5 repetitions (reps) per minute. These specifications were employed to allow for an external power output of 100 W during the test. Such an absolute test for squat endurance was included because many military and industrial tasks involve repetitive loading with similar load and power demands (e.g., loading medical supplies, munitions, food, etc.). Performance was measured as the total number of reps performed at the set speed of movement to volitional fatigue.

Military Occupational Tests

1-RM box lift. The 1-RM box lift was determined as the maximal mass that could be lifted one time from the floor to a platform (1.32 m) by using a steel box with handles (initial mass = 20.45 kg with dimensions of 0.47 m · 0.23 m · 0.31 m). The 1.32-m height was specifically chosen because it is the height from the ground to the bed of a U.S. Army utility truck. Thus, this functional lifting task was one that a soldier could encounter during a typical work day. A straight-back lifting technique, using primarily the lower-body musculature to perform the lift, was utilized and the subjects were not permitted to assist the movement of the box with their chest, abdomen, or thighs. Thus, this lift was one dynamic movement with a final pushing of the box outward, onto the platform surface, thereby requiring a significant contribution from the upper-body musculature. Three to five trials were permitted with the mass incrementally added to the box until the subject could not successfully complete the lift using proper form. Performance was measured as the maximum total mass (kg) successfully lifted.

Repetitive box lift. By using the same box as described above (i.e., empty box mass of 20.45 kg), the goal of the repetitive box lift test was to load the maximum number of boxes as fast as possible from the floor to a 1.32 m platform in 10 min. The task required the subject to move at a volitional pace between two platforms that were placed 2.4 m apart, lifting one box at a time onto each platform. After each successful lift, two investigators returned the box to the floor while the subject was lifting the box at the other platform, etc. This test simulated a maximal paced repetitive loading task with a weight similar to many box loads used in the military (e.g., food, munitions, medical supplies, etc.).

2-Mile loaded run. A 2-mile loaded run was performed to simulate a forced movement with a rucksack load in the field. It was operationally defined as the time required to run 2 miles on an all-weather 400-m track while carrying a 34.1-kg U.S. Army rucksack. The rucksack consisted of an external frame with the load properly positioned within the rucksack representative of a typical sustenance load for a soldier.

U.S. Army Physical Fitness Test Measures

U.S. Army Physical Fitness Tests (APFT) were conducted by the same investigator for all subjects at all time points according to the guidelines and procedures given in the U.S. Army physical fitness training manual (36). This allowed for the same evaluation of the form used for all acceptable push-up and sit-up repetitions that were counted. The APFT tasks were included in this study so that a greater understanding could be gained from relationships among APFT and other strength, power, endurance, and military occupational tasks. For push-ups and sit-ups, subjects performed the maximum number that could be correctly completed in 2 min. During push-up testing, subjects descended until the upper arms were parallel to the floor. For sit-ups, the feet were held while the subject raised the elbows passed their bent knees and then returned to the starting position. Performance in the 2-mile run was measured as the minimum time (seconds) required to run 2 miles on an all-weather 400-m track. Ten-minute rest periods were carefully controlled between each test according to APFT requirements. Additional training and supervision from former U.S. Army officers and enlisted personnel enhanced quality assurance for these tests with previous experience in conducting such testing during active duty assignments.

Exercise Training Programs

All workouts started with a general warm-up and included cool-down periods (i.e., low-intensity aerobic exercise, stretching, etc.) of approximately 5–10 min. A trainer supervised all subjects so that all essential program characteristics were strictly enforced. Specifically, trainers were responsible for seeing that exercise prescriptions were properly carried out and achieved during a workout (e.g., velocity of movement, appropriate spotting, appropriate safety considerations, prescribed rest periods, and proper hydration requirements). Also, it has been recently demonstrated that direct supervision of resistance training is vital to optimize strength performance adaptations (23).

The TP, TH, UP, UH, and FLD groups performed 24-wk (macrocycle) periodized resistance training programs divided into two 12-wk meso-cycles separated by 3 wk of active rest (i.e., period of low-intensity recreational activities) (Tables 2–4) (8). Periodization of resistance training was incorporated into these training programs to optimize the strength and power adaptations and prevent boredom and overtraining (9). The AER training program also was performed over a 24-wk period divided into two 12-wk mesocycles separated by the same active recovery period (Table 4). Two resistance training groups performed exercises for all major muscle groups (TP and TH), whereas the other two resistance training groups performed only exercises for the upper-body musculature (UP and UH). Within these four groups, one total- and one upper-body group performed strength/power [P] training (i.e., explosive, more rapid movements using moderate to very heavy training loads [resistances] and fewer repetitions), whereas the other total- and upper-body groups performed strength/hypertrophy [H] type training programs (i.e., slower, more controlled body building exercises using moderate to heavy training loads and higher numbers of repetitions). These different training groups enabled comparisons among different training program designs (i.e., strength/power versus

TABLE 2. One 12-wk mesocycle of the total strength/power and upper strength/power periodized, heavy-resistance training programs.

	Total Strength/Power					
	MIC 1		MIC 2		MIC 3	
	rep	m	rep	m	rep	m
Monday (3 sets per exercise)						
DB clean & press	8		5		3	
Leg curl	8	2	8	2	6	2
Dumbbell incline press	8		5		3	
Front pull-down	8	2	8	2	6	2
Squat	8		5		3	
Inclined sit-up	15	2	15	2	15	2
Upright row	8		8		5	
Dumbbell row	8	2	8	2	5	2
Wednesday (3 sets per exercise)						
High pull	8		5		3	
Leg curl	8	2	8	2	6	2
Bench press	8		5		3	
Seated row	8	2	5	2	5	2
Dumbbell press	8		5		3	
Lat. pull-down	8	2	8	2	6	2
Calf raise	8		8		8	
Abdominal crunch	25	2	25	2	25	2
Friday (3 sets per exercise)						
High pull	8		5		3	
Weighted sit-up	8	2	10	2	10	2
Squat	8		5		3	
Calf raise	8	2	8	2	8	2
Narrow bench press	8		5		3	
Dumbbell row	8	2	5	2	5	2
Leg extension	8		8		6	
Leg curl	8	2	8	2	6	2

	Upper Strength/Power					
	MIC 1		MIC 2		MIC 3	
	rep	m	rep	m	rep	m
Monday (3 sets per exercise)						
Bench press	8		5		3	
Seated row	8	2	5	2	5	2
Dumbbell press	8		5		3	
Lat. pull-down	8	2	8	2	6	2
EZ bar biceps curl	8		8		6	
Triceps push-down	8	2	8	2	6	2
Inclined sit-up	20		20		20	
Back extension	8	2	10	2	8	2
Wednesday (3 sets per exercise)						
Dumbbell incline press	8		5		3	
Front pull down	8	2	8	2	6	2
Upright row	8		5		5	
Dumbbell row	8	2	5	2	5	2
Dumbbell curl	8		8		6	
Dumbbell triceps ext.	8	2	8	2	6	2
Abdominal crunch	25	1	25	1	25	1
Friday (3 sets per exercise)						
Bench press	8		5		3	
Seated row	8	2	5	2	5	2
Dumbbell press	8		5		3	
Lat. pull-down	8	2	8	2	6	2
EZ bar biceps curl	8		8		6	
Triceps push-down	8	2	8	2	6	2
Weighted sit-up	8		10		8	
Back extension	8	2	10	2	8	2

MIC, microcycle; rep, repetitions; m, minutes of recovery between sets of alternating exercises; DB, dumbbell.

strength/hypertrophy) and between upper- versus total-body resistance training.

The FLD group performed ballistic plyometric and partner-resisted exercises to determine the viability of an “in the field” training program designed for use by soldiers during specific operations when training facilities are not accessible. Lastly, an aerobic group (AER), which emphasized endurance training while only performing very low resistance (<5 kg) and very low volume resistance-band exercises (needed for removal of preferential experimental effects for those not performing both styles of programs), was included for comparison with the other resistance training groups. Exercises, numbers of repetitions, numbers of sets, and the length of rest periods were designed according to each specific training program and are shown in detail in Table 2 (strength/power), Table 3 (strength/hypertrophy), and Table 4 (field and aerobic). Repetitions were targeted within a ± 2 repetition zone from the listed number shown in the tables.

All of the resistance training groups also performed supplemental aerobic exercise after their respective resistance training sessions. The aerobic exercise consisted of 25–35 min of running with cycling and stair-stepping providing variation. In contrast, the AER group used endurance exercise as their primary mode with supplemental resistance band exercises. The endurance exercise consisted of about 35–40 min of running twice per week and 25–35 min of treadmill running, cycling, or stair-stepping once per week to provide variation in exercise and volume. All subjects were taught to assess heart rate via palpation, and their accuracy was randomly tested using Polar heart rate monitors. The intensity of the target heart rate training zone was 70 to 85% of the estimated maximum heart rate (220 − age).

Periodized Resistance Training

Initial training loads (kg) were determined, in part during the familiarization phase of the study, and using approximate percentages of the 1-RM. Then using standard trial and error methods (i.e., unload if too few reps were performed and load if too many reps were performed), the loads for each set were modulated based on performance in reference to the target RM training number (±2 reps). The personal trainer was responsible for this careful modulation of the training load progression (23).

The choice of exercises primarily differed between strength/power and strength/hypertrophy training programs due to the inclusion of two power exercises (i.e., high pull and dumbbell power clean and press). Moreover, the strength/power training groups (TP, UP) were specifically taught to lift the weights powerfully (ballistic lifting), using a higher velocity of movement during all exercises to facilitate the power component of the training program (24,25). In contrast, the strength/hypertrophy training groups (TH, UH) were specifically taught to move the resistance in a controlled manner (slower velocity) during the concentric and eccentric movements typical of body building protocols (8).

TABLE 3. One 12-wk mesocycle of the total strength/hypertrophy and upper strength/hypertrophy periodized, heavy-resistance training programs.

	Total Strength/Hypertrophy							Upper Strength/Hypertrophy					
	MIC 1		MIC 2		MIC 3			MIC 1		MIC 2		MIC 3	
	rep	s	rep	s	rep	s		rep	s	rep	s	rep	s
Monday (3 sets per exercise)							Monday (3 sets per exercise)						
Squat	12	90	10	90	8	60	Bench press	12	90	10	90	8	60
Leg extension	12	60	10	60	8	30	Seated row	12	90	10	90	8	60
Leg curl	12	60	10	60	8	30	Dumbbell press	12	60	10	60	8	60
Dumbbell incline press	12	60	10	60	8	60	Latissimus pull-down	12	60	10	60	8	60
Chest fly	12	60	10	60	8	60	EZ bar biceps curl	12	30	10	30	8	30
Front pull-down	12	60	10	60	8	60	Triceps push-down	12	30	10	30	8	30
Upright row	12	30	10	30	8	30	Rotational ab. crunch	25	60	25	60	30	30
Dumbbell row	12	30	10	30	8	30	Back extension	12	60	10	60	8	30
Rotational ab. crunch	25	60	25	60	25	60							
Wednesday (3 sets per exercise)							Wednesday (3 sets per exercise)						
Leg extension	12	90	10	90	8	30	Dumbbell incline press	12	90	10	90	8	60
Leg curl	12	90	10	90	8	30	Front pull-down	12	90	10	90	8	60
Calf raise	12	60	10	60	8	30	Upright row	12	60	10	60	8	60
Bench press	12	90	10	90	8	60	Dumbbell row	12	60	10	60	8	60
Seated row	12	90	10	90	8	60	Dumbbell curl	12	30	10	30	8	30
Triceps push-down	12	30	10	30	8	30	DB triceps extension	12	30	10	30	8	30
EZ bar biceps curl	12	30	10	30	8	30	Sit-up	25	60	25	60	30	60
Sit-up	25	60	25	60	25	60							
Friday (3 sets per exercise)							Friday (3 sets per exercise)						
Squat	12	90	10	90	8	60	Bench press	12	90	10	90	8	60
Leg curl	12	60	10	60	8	30	Seated row	12	90	10	90	8	60
Calf raise	12	60	10	60	8	30	Dumbbell press	12	60	10	60	8	60
Narrow bench press	12	90	10	90	8	60	Latissimus pull-down	12	60	10	60	8	60
Dumbbell row	12	90	10	90	8	30	EZ bar biceps curl	12	30	10	30	8	30
DB triceps extension	12	30	10	30	8	30	Triceps push-down	12	30	10	30	8	30
Dumbbell curl	12	30	10	30	8	30	Rotational ab. crunch	25	60	25	60	30	30
Abdominal crunch	25	60	25	60	25	60	Back extension	12	60	10	60	8	30

MIC, microcycle; rep, repetitions; s, seconds of recovery between sets; ab, abdominal; DB, dumbbell.

Total- (TP) and upper- (UP) strength/power groups. Differentiation of designs between the total- and upper-body programs were that the TP program included large muscle group exercises for both upper- and lower-body musculature, whereas the UP program incorporated the same upper-body exercises with additional upper-body exercises in place of the hip and leg exercises to help equate total work among programs (Table 2). Both groups performed alternating sets of two exercises (e.g., bench press and seated row) to increase the time efficiency of the workout and rest between sets. Specifically, a set of one exercise (e.g., bench press) would, after the appropriate rest, be followed by a set of an antagonistic exercise (e.g., seated row) until three sets of each exercise were completed for both. The rest time between sets of alternating exercises during all three microcycles was 2 min so that 4–5 min elapsed between sets of any one exercise thereby promoting strength and power development (25).

Total- (TH) and upper- (UH) strength/hypertrophy groups. The differentiation of design between the total-body and upper-body programs was the elimination of hip and leg exercises from the UH training program with the addition of upper-body exercises in place of the hip and leg exercises to help equate total work among programs. Both groups performed three consecutive sets of each exercise using rest intervals as described in the training logs (Table 3).

Field and Aerobic Training

Field group. Each 12-wk mesocycle for the FLD training program consisted of one 4-wk microcycle followed by one 8-wk microcycle (Table 4). Subjects in the FLD group performed ballistic plyometric (i.e., bounds and jumps), partner-resisted (i.e., exercises performed with towels where the partner would provide the resistance against which the subject pulled or pushed), and other common exercises (e.g., push-ups, sit-ups, self-squats, etc.). The women trained in pairs and personal trainers coordinated the workouts. The partner exercises included upright row/triceps push-down, narrow pull-down/hammer curl, curl/triceps push-down, and seated row. Each of these exercises was performed simultaneously by pairs of subjects. For example, the upright row/triceps push-down exercises were combined into one activity for two subjects. Standing facing each other, one subject gripped the middle of a rolled towel with an overhand grip and performed an upright row by pulling upwards, while the other subject, gripping the two ends of the towel, simultaneously performed the triceps push-down by pushing downward against the resistance provided by the partner. To incorporate a progressive component in this program, the numbers of repetitions were increased after the first 4-wk microcycle for exercises where additional resistance could not be added (i.e., self-squat, lateral lunges, dumbbell good-morning, etc.). For partner-resisted exercises (including push-ups), the number of repetitions were reduced after the

TABLE 4. One 12-wk mesocycle of the field and aerobic training programs.

	Field					
	MIC 1		MIC 2 (8 wk)			
	rep	s	rep	s	Aerobic	
Monday (3 sets per exercise)					Monday	
Self-squat	20	60	25	60	Stretching and shoulder, arm, ankle, and neck circles	20-s duration each
Lateral lunges	12	60	14	60		
DB goodmorning	12	60	14	60	Jumping jacks	20-s duration
Wide push-ups	12	60	10	60	Group running	35 min, HR 144–156
Upright row/triceps push-down (P)	12	60	10	60	Quarter ROM squats	3 circuits of 10 repetitions per exercise with 1-min rests between circuits
Narrow pull-down/ hammer curl (P)	12	60	10	60	Chest squeeze (RB)	
					Tri. ext. squeeze (RB)	
Sit-up	25	60	25	60	Spine erector	
					Squeeze	
					Abdominal crunch	
Wednesday (3 sets per exercise)					Wednesday	
Isometric wall squat	20	60	30s	60	Stretching and shoulder, arm, ankle, and neck circles	20-s duration each
DB goodmorning	12	60	15	60		
Self-heel raise	20	60	25	60	Jumping jacks	20-s duration
Partner push-ups	12	60	10	60	Aerobic exercise	25 min, HR 144–156
Seated row (P)	12	60	10	60	Quarter ROM squats	3 circuits of 10 repetitions per exercise with 1-min rests between circuits
Biceps curl/triceps push-down (P)	12	60	10	60	Pull-down sqz (RB)	
Sit-up	25	60	25	60	Row squeeze (RB)	
					Rear deltoid sqz (RB)	
					Biceps curl sqz (RB)	
Friday (3 sets per exercise)					Friday	
1 Leg plyo-bounds	6	60	8	60	Stretching and shoulder, arm, ankle, and neck circles	20-s duration
2 Leg plyo-jumps	6	60	8	60		
Lunges	12	60	14	60	Jumping jacks	20-s duration each
Narrow push-ups	12	60	10	60	Group running	35 min, HR 144–156
Seated row (P)	12	60	10	60	1/4 ROM wide squats	3 circuits of 10 repetitions per exercise with 1-min rests between circuits
One arm DB curl	12	60	14	60	Standing calf raise	
Abdominal crunch	25	60	25	60	Hip abductions	

MIC, microcycle; rep, repetitions; s, seconds of recovery between sets; DB, dumbbell; Tri, triceps; P, partner resistance exercises; RB, resistance-band exercises; Squeeze (Sqz), 10-s isometric contraction; Plyo, plyometric exercise; ROM, range of motion; HR, heart rate.

first microcycle and partners were instructed to perceptually increase the applied resistance.

Aerobic group. Subjects in the AER group performed very light resistance-band exercises (5 kg or less) to give them a similar component to the other groups in order to help adherence and compliance to the total program (Table 4).

Statistical Analyses

Data are presented as the mean ± one standard deviation. A two-way analysis of variance (ANOVA) (3 × 6) with repeated measures was used for analysis of the data and a Tukey HSD *post hoc* was used when appropriate to determine pair-wise differences (Statistica Version 4.1, StatSoft, Inc., Tulsa, OK). Before the analyses of the data, all assumptions for linear statistics were performed, and the data set met each criterion. All values for the women's groups (T0, T3, and T6) were compared with the MEN group by using separate one-way ANOVAs for each variable. Selected Pearson-product moment correlation coefficients were computed to examine certain bivariate relationships. Statistical power (n size calculations) ranged from 0.80 to 0.95 at the P-value selected to establish significance in this study (0.05) (nQuery Advisor® software, Statistical Solutions, Saugus, MA).

RESULTS

Body Composition

Significant interaction occurred among groups for body mass over the training period (Table 5). Group × time interactions among groups for fat-free mass ($P = 0.07$) and percent body fat were not significant. No differences were observed among groups in body mass, fat-free mass, or percent body fat at T3 or T6. Significant differences among groups in the change in body mass from T0 to T6 included TP > UP and AER. Body mass (78.7 ± 9.4 kg) and fat-free mass (65.3 ± 5.7 kg) in the MEN group were significantly greater than all women's groups at all time points. Percent body fat in the MEN group (16.5 ± 6.4%) was significantly lower than all women's groups at all time points.

Resistance exercise performance

1-RM squat. Significant interaction occurred among groups for 1-RM squat over the training period (Fig. 1A). Significant differences among groups in 1-RM squat performance at T3 included TP and TH > AER. At T6, significant differences among groups in 1-RM squat included TP and TH > UP, UH, FLD, and AER. The 1-RM squat in the MEN group (100.6 ± 24.5 kg) was significantly heavier than all women's groups at all time points.

TABLE 5. Body composition changes with training over 3 (T3) and 6 (T6) months.

Group	T0	T3	T6	Δ (T6-T0)
Body mass (kg)				
Total strength/power	64.1 ± 8.8	65.8 ± 10.1	67.0 ± 10.2*	2.99 ± 3.6
Total strength/hypertrophy	63.2 ± 7.0	63.7 ± 7.1	64.6 ± 7.4	1.32 ± 2.3
Upper strength/power	66.7 ± 10.7	66.5 ± 10.7	66.4 ± 9.0	−0.29 ± 3.5
Upper strength/hypertrophy	65.7 ± 12.1	65.6 ± 11.5	66.8 ± 11.9	1.14 ± 2.6
Field	67.7 ± 12.2	67.6 ± 12.2	68.8 ± 13.1	1.06 ± 3.1
Aerobic	68.9 ± 10.6	67.5 ± 11.7	68.2 ± 11.1	−0.75 ± 2.1
Fat-free mass (kg)				
Total strength/power	47.2 ± 4.7	48.3 ± 5.0	49.2 ± 5.4*	1.98 ± 1.8
Total strength/hypertrophy	47.9 ± 3.5	48.8 ± 3.7	49.1 ± 3.7	1.22 ± 1.3
Upper strength/power	49.2 ± 5.4	49.5 ± 5.9	49.7 ± 5.4	0.55 ± 1.5
Upper strength/hypertrophy	47.9 ± 5.6	48.6 ± 6.3	49.1 ± 5.9	1.20 ± 1.9
Field	47.6 ± 7.0	47.7 ± 6.2	49.5 ± 6.1* †	1.91 ± 3.2
Aerobic	47.4 ± 2.9	46.8 ± 3.8	48.4 ± 3.6	0.99 ± 2.0
Body fat (%)				
Total strength/power	25.8 ± 5.9	26.0 ± 5.7	26.1 ± 5.4	0.35 ± 3.2
Total strength/hypertrophy	23.9 ± 5.0	23.0 ± 4.7	23.5 ± 4.8	−0.36 ± 1.7
Upper strength/power	25.5 ± 6.1	24.9 ± 5.8	24.7 ± 5.3	−0.85 ± 2.8
Upper strength/hypertrophy	26.3 ± 5.3	25.5 ± 4.6	25.9 ± 5.3	−0.46 ± 2.8
Field	29.2 ± 5.5	28.6 ± 6.4	27.0 ± 6.7	−2.21 ± 4.5
Aerobic	30.3 ± 7.5	29.6 ± 7.9	28.0 ± 7.1	−2.23 ± 2.6

Values are mean ± SD; T0, baseline testing.
* $P \leq 0.05$ vs corresponding T0 value; † $P \leq 0.05$ vs corresponding T3 value.

1-RM bench press. Significant interaction was observed among groups for 1-RM bench press over the training period (Fig. 1B). Significant differences among groups in 1-RM bench press performance at T3 included TP, UP, and UH > AER. At T6, significant differences among groups in 1-RM bench press included TP, TH, UP, and UH > AER; and TP > FLD. The 1-RM bench press in the MEN group (81.0 ± 19.7 kg) was significantly heavier than all women's groups at all time points.

1-RM high pull. Significant interaction occurred among groups for 1-RM high pull over the training period (Fig. 1C). Significant differences among groups in 1-RM high pull performance at T3 included TP > FLD and AER. At T6, significant differences among groups in 1-RM high pull included TP > all other training groups. The 1-RM high pull in the MEN group (58.8 ± 9.6 kg) was significantly heavier than all women's groups at all time points.

Squat jump power. Significant interaction occurred among groups for peak squat jump power over the training period (Fig. 2A). Significant differences among groups in squat jump power at T6 included TP > AER.

Bench press throw power. Significant interaction occurred among groups for the peak bench throw power over the training period (Fig. 2B). Significant differences among groups in bench throw power at T3 included TP > AER. At T6, significant differences among groups in bench throw power included TP and UP > AER.

Squat endurance. Significant interaction occurred among groups for squat endurance performance over the training period (Fig. 2C). Significant differences among groups in squat endurance performance at T6 included TH > UP, FLD, and AER. Squat endurance performance in the MEN group (59.5 ± 24.3 reps) was significantly greater than all women's groups at T0. At T6, squat endurance performance did not differ among the MEN, TP, and TH groups.

Military-Relevant Occupational Task Performances

1-RM box lift. Significant interaction occurred among groups for 1-RM box lift over the training period (Fig. 3A). Significant differences among groups in 1-RM box lift performance at T6 included TP > AER. The 1-RM box lift in the MEN group (57.4 ± 12.3 kg) was significantly heavier than all women's groups at all time points.

Repetitive box lift. Significant interaction occurred among groups for repetitive box lift over the training period (Fig. 3B). Significant differences among groups in repetitive box lift performance at T3 and T6 included TP, TH, UP, and UH > FLD and AER. The average number of boxes lifted in the MEN group (131.0 ± 22.0 boxes) was significantly greater than all women's groups at T0. At T6, repetitive box lift performance did not differ among the MEN, TP, TH, UP, and UH groups.

2-Mile loaded run. Group × time interaction for the 2-mile loaded run ($P = 0.068$) was not significant (Fig. 3C). Significant differences among groups in 2-mile loaded run performance at T6 included TP, TH, and UP < FLD and AER; and UH < AER. The MEN group ran the 2-mile loaded run in significantly less time (1702.5 ± 331.1 s) than all women's groups at T0. Two-mile loaded run time did not differ among the MEN, TP, TH, UP, and UH groups at T6.

U.S. Army Physical Fitness Testing Performances

Push-ups. Significant interaction occurred among groups for push-ups over the training period (Table 6). Significant differences among groups in push-up performance at T6 included TP, TH, UP, and UH > AER; and UP > FLD. Push-up performance in the MEN group (49.2 ± 16.0 reps) was significantly greater than all women's groups at T0. Push-up performance, however, did not differ among the MEN, TP, TH, UP, and UH groups at T6.

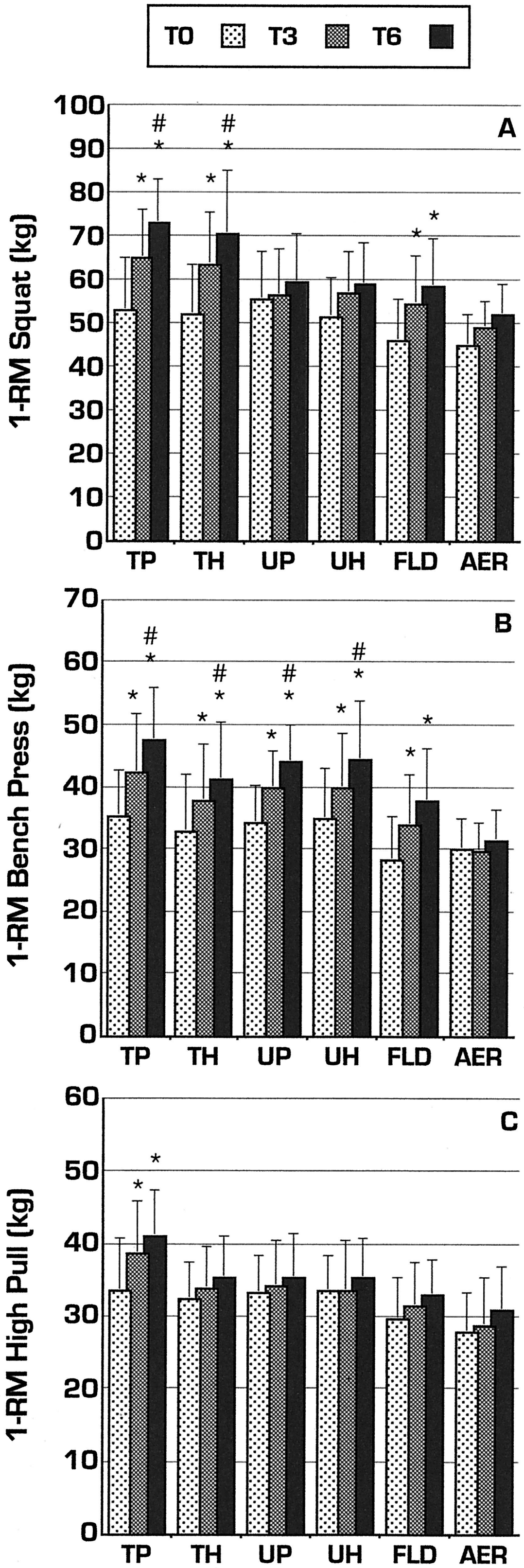

FIGURE 1—Comparison of women's 1-RM squat (A), bench press (B), and high pull performances (C) before (T0) and after 3 (T3) and 6 months of training (T6) among total strength/power (TP), total strength/hypertrophy (TH), upper strength/power (UP), upper strength/hypertrophy (UH), field (FLD), and aerobic training groups (AER). Values are means ± SD; * $P \leq 0.05$ vs corresponding T0 value, # $P \leq 0.05$ vs corresponding T3 value.

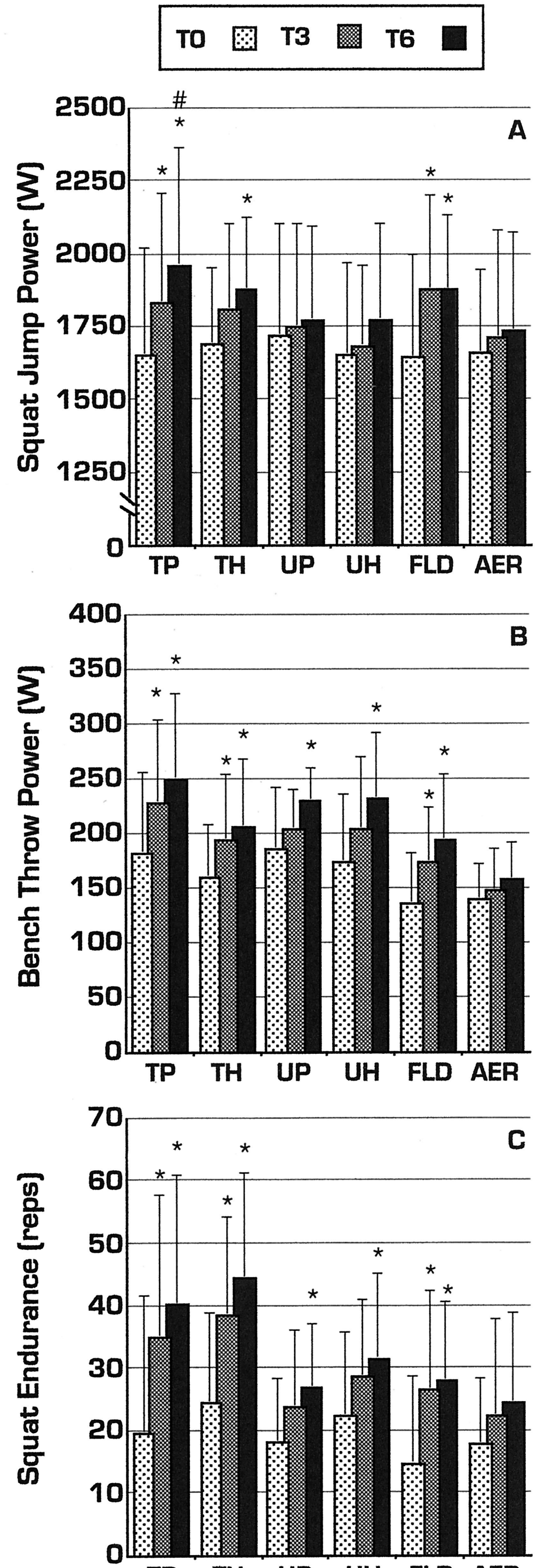

FIGURE 2—Comparison of women's squat jump power (A), bench throw power (B), and squat endurance performances (C) before (T0) and after 3 (T3) and 6 months of training (T6) among total strength/power (TP), total strength/hypertrophy (TH), upper strength/power (UP), upper strength/hypertrophy (UH), field (FLD), and aerobic training groups (AER). Values are means ± SD; * $P \leq 0.05$ vs corresponding T0 value, # $P \leq 0.05$ vs corresponding T3 value.

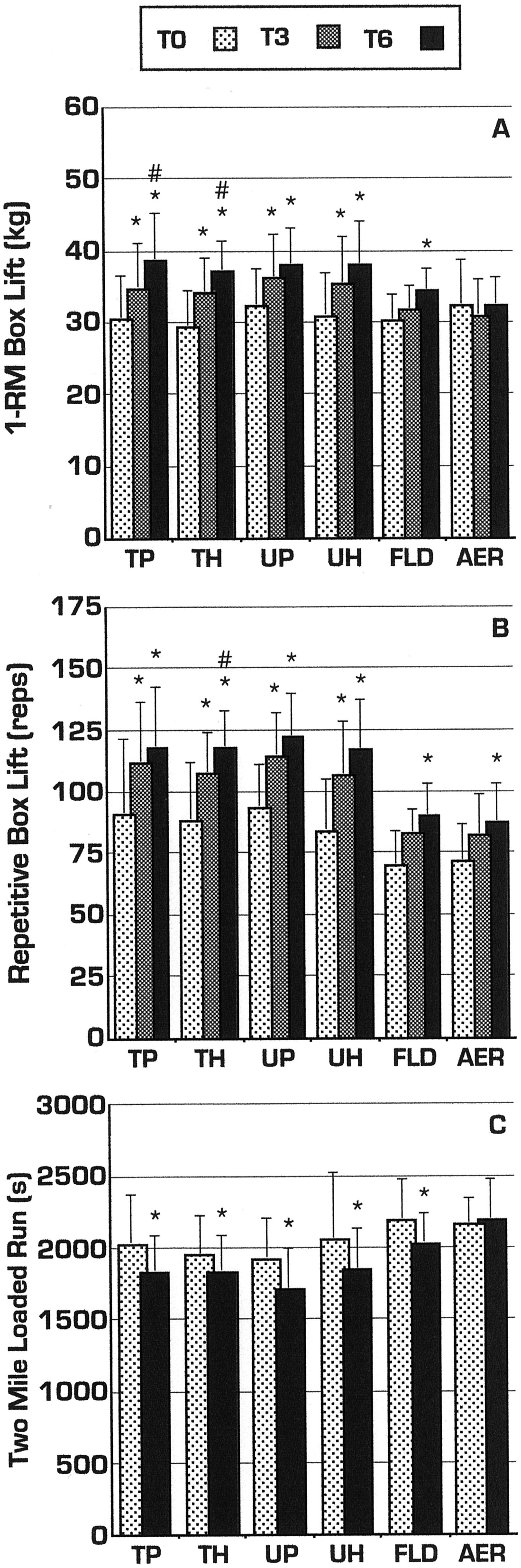

FIGURE 3—Comparison of women's 1-RM box lift (A), repetitive box lift (B), and 2-mile loaded run performances (C) before (T0) and after 3 (T3) and 6 months of training (T6) among total strength/power (TP), total strength/hypertrophy (TH), upper strength/power (UP), upper strength/hypertrophy (UH), field (FLD), and aerobic training groups (AER). Values are means ± SD; * $P \leq 0.05$ vs corresponding T0 value, # $P \leq 0.05$ vs corresponding T3 value.

TABLE 6. U.S. Army Physical Fitness Test changes over 6 (T6) months of training.

Group	T0	T6	Δ (T6-T0)
Push-ups (reps)			
Total strength/power	22.2 ± 8.6	35.3 ± 9.4*	13.1 ± 7.2
Total strength/hypertrophy	20.3 ± 13.0	35.6 ± 17.8*	15.3 ± 9.2
Upper strength/power	25.7 ± 15.4	43.0 ± 10.5*	17.3 ± 10.1
Upper strength/hypertrophy	19.4 ± 12.1	37.4 ± 13.3*	18.0 ± 6.6
Field	17.9 ± 12.8	27.1 ± 11.5*	9.2 ± 10.0
Aerobic	15.6 ± 12.3	18.7 ± 12.3	3.1 ± 7.9
Sit-ups (reps)			
Total strength/power	42.2 ± 18.2	67.5 ± 11.9*	25.3 ± 10.9
Total strength/hypertrophy	36.8 ± 14.9	58.1 ± 14.7*	21.3 ± 12.3
Upper strength/power	45.9 ± 21.9	69.2 ± 14.9*	23.3 ± 10.9
Upper strength/hypertrophy	36.0 ± 18.1	61.9 ± 14.6*	25.9 ± 12.7
Field	34.7 ± 12.9	53.6 ± 7.8*	18.9 ± 11.8
Aerobic	28.8 ± 21.9	37.8 ± 20.8	9.0 ± 8.3
2-Mile run (s)			
Total strength/power	1218 ± 213	1138 ± 156*	−80 ± 143
Total strength/hypertrophy	1204 ± 269	1119 ± 123*	−85 ± 193
Upper strength/power	1124 ± 164	1061 ± 113*	−63 ± 81
Upper strength/hypertrophy	1204 ± 225	1101 ± 176*	−104 ± 67
Field	1319 ± 191	1238 ± 219*	−81 ± 87
Aerobic	1348 ± 204	1192 ± 126*	−156 ± 123

Values are mean ± SD; T0, baseline testing; reps, repetitions.
* $P \leq 0.05$ vs corresponding T0 value.

Sit-ups. Significant interaction occurred among groups for sit-ups over the training period (Table 6). Significant differences among groups in sit-up performance at T6 included TP, TH, UP, and UH > AER; and UP > FLD. Sit-up performance in the MEN group (48.8 ± 14.3 reps) was significantly greater than the AER group at T0. At T6, sit-up performance did not differ among the MEN, TH, UH, FLD, and AER groups. Interestingly, the TP and UP groups each performed a significantly greater number of sit-ups than the MEN group at T6.

2-Mile run. Group × time interaction for the 2-mile run was not significant (Table 6). Significant differences among groups in two mile run performance at T6 included TH, UP, and UH < FLD; and UP < AER. Two-mile run time in the MEN group (1012.6 ± 174.8 s) was significantly faster than all women's groups at T0. However, the two-mile run time did not differ among the MEN, UP, and UH groups at T6.

Comparisons to Values for Men

In general, physical training by women reduced the gender differences in performance. Figures 4–6 show the gains made by the different groups as compared with the male mean (percentage) for the given performance. Although all groups made improvements in various physical performances in relationship to the male normative value, the following groups were the highest in their improvements. The TP group had the highest improvements on the male norm in 1-RM squat, 1-RM bench press, 1-RM high pull, 1-RM box lift, and sit-ups. The UP group had the highest improvement on the male norm in repetitive box lift, 2-mile loaded run, push-ups, and 2-mile run. The TH group was the highest for the squat endurance test.

DISCUSSION

Few long-term (e.g., > 4 months) training studies in women have been undertaken, making our understanding of

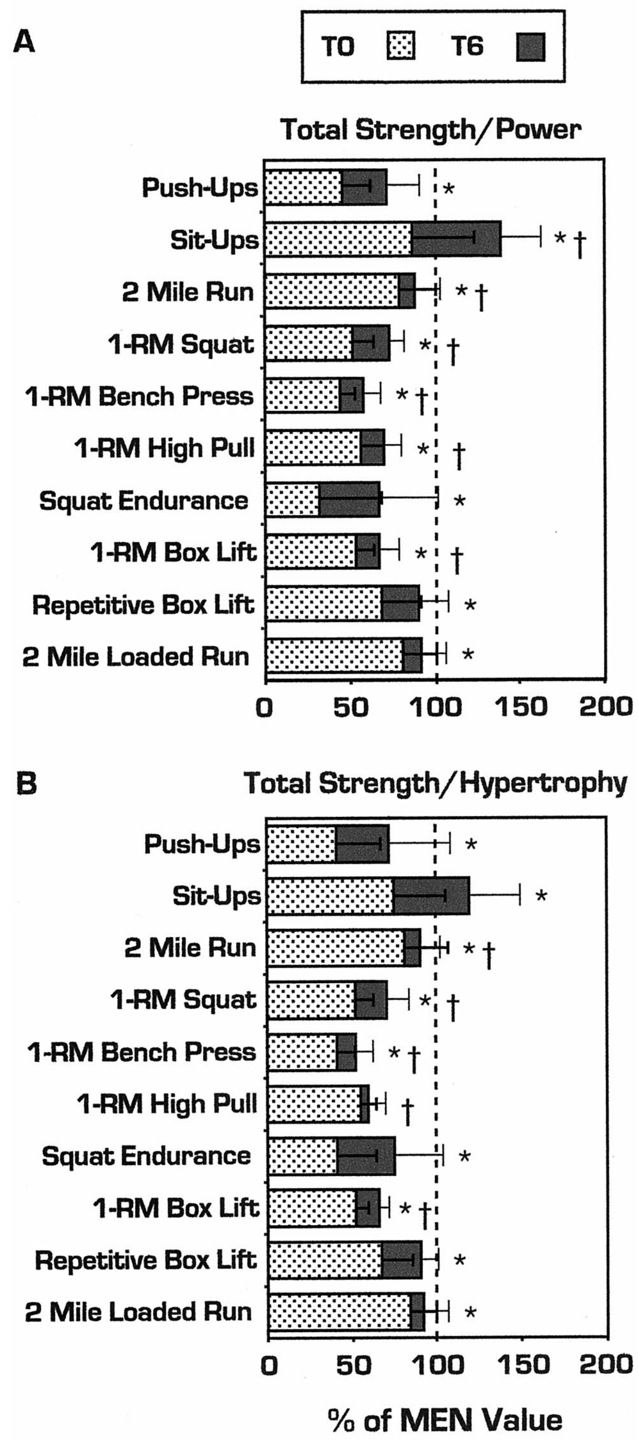

FIGURE 4—Comparison of U.S. Army Physical Fitness Test, strength, endurance, and military occupational task performances among untrained (T0) and resistance trained women (T6) and nonresistance trained men (as a percentage) for total strength/power (A) and total strength/hypertrophy training groups (B). Values (means ± SD) are expressed as the average percentage of the MEN group; * $P \leq 0.05$ vs corresponding T0 value, † $P \leq 0.05$ vs MEN value (at T6 only).

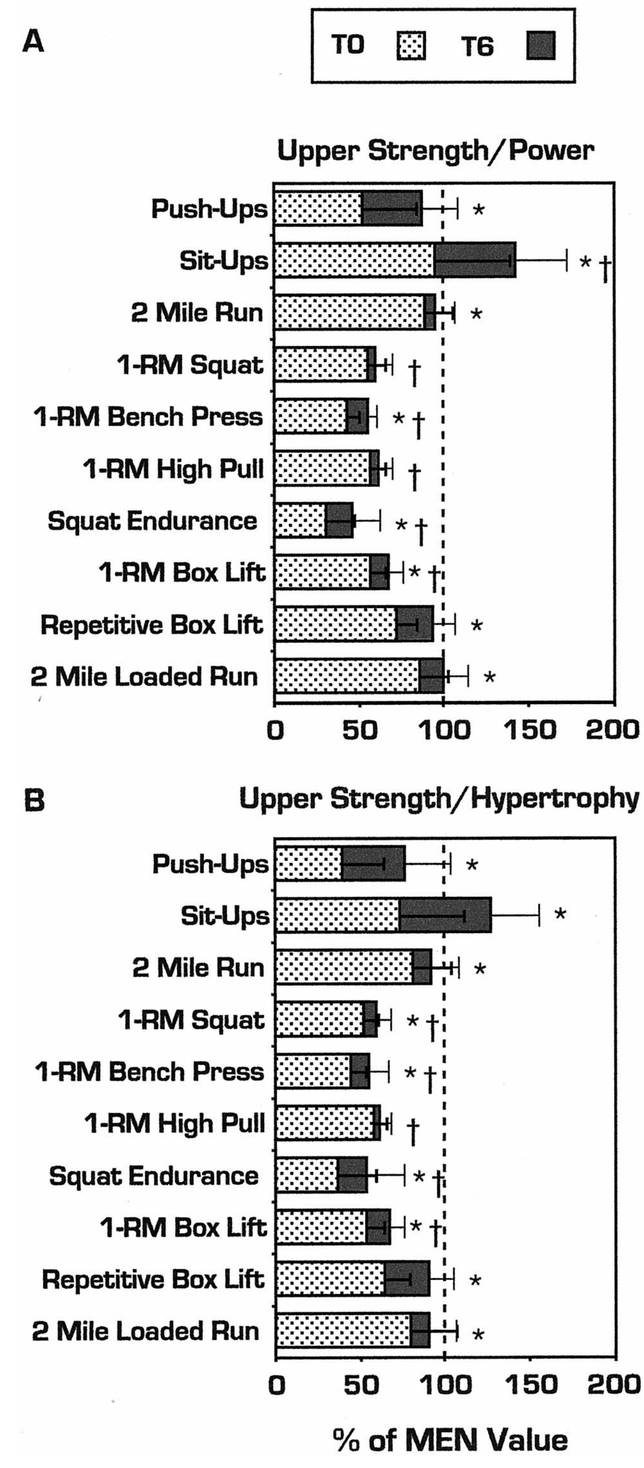

FIGURE 5—Comparison of U.S. Army Physical Fitness Test, strength, endurance, and military occupational task performances among untrained (T0) and resistance trained women (T6) and nonresistance trained men (as a percentage) for upper strength/power (A) and upper strength/hypertrophy training groups (B). Values (means ± SD) are expressed as the average percentage of the MEN group; * $P \leq 0.05$ vs corresponding T0 value, † $P \leq 0.05$ vs MEN value (at T6 only).

the long-term adaptations associated with resistance training limited (5,32). Furthermore, no study has ever tried to partial out program differences related to subsequent performance adaptations with long-term training. In general, the primary findings of this study were that periodized progressive resistance training was associated with continued significant improvements in high-intensity physical performances over the entire 6-month training period. As expected, aerobic training did not impact strength/power performances. Differences in the physical performance

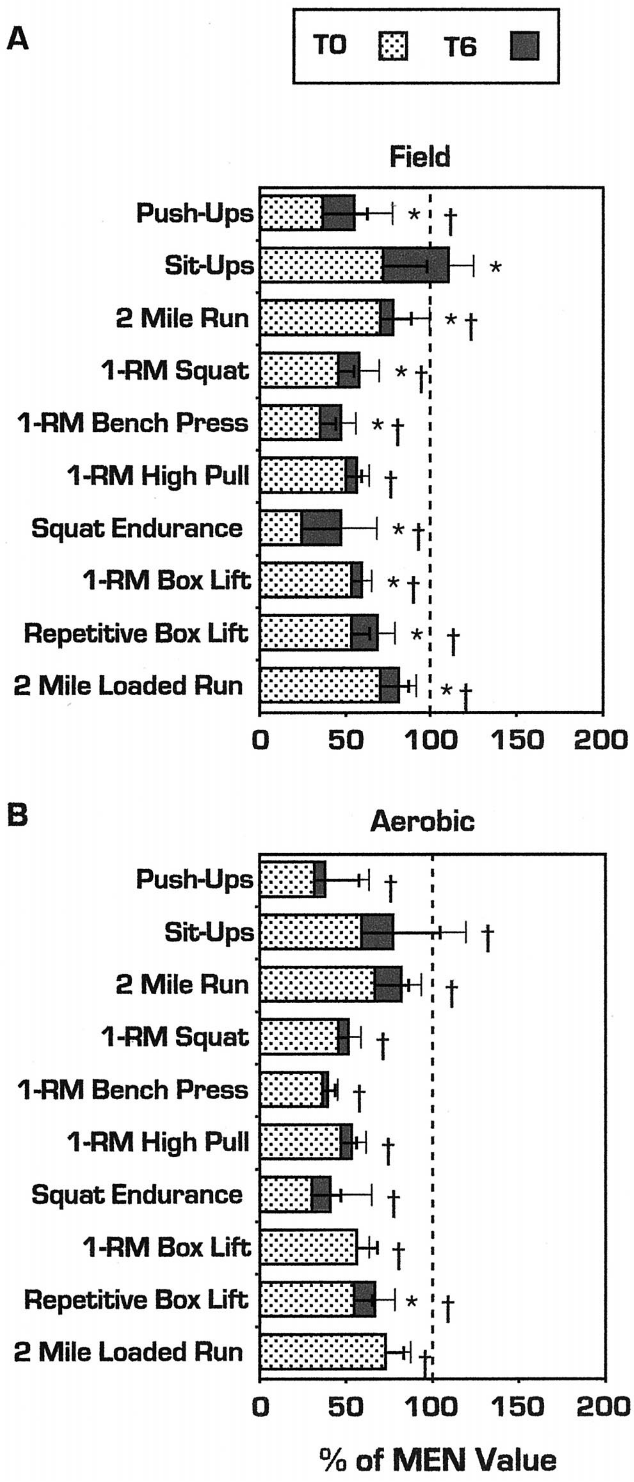

FIGURE 6—Comparison of U. S. Army Physical Fitness Test, strength, endurance, and military occupational task performances among untrained (T0) and resistance trained women (T6) and nonresistance trained men (as a percentage) for field (A) and aerobic training groups (B). Values (means ± SD) are expressed as the average percentage of the MEN group; * $P \leq 0.05$ vs corresponding T0 value, † $P \leq 0.05$ vs MEN value (at T6 only).

adaptations after resistance training were specific to the characteristics of the program (e.g., inclusion of whole-body ballistic exercises on power performances). Upper-body resistance training appears to dramatically influence women's performances in occupational tasks over the first 6 months of conditioning. The extent to which women's military-relevant occupational task performances were enhanced, again, depended largely upon the type of resistance training program utilized. In addition, physical training did help to reduce gender differences but the gains were highly specific to the type of training activity performed.

We had hypothesized that training-related adaptations would be specifically linked to the type of training program used. The results of this investigation support our hypothesis and the plethora of research related to this concept of training specificity (8). For example, the TP group made the most dramatic increases in 1-RM high pull strength. This was mediated by the inclusion of structural lifts in the program (e.g., high pulls, and dumbbell clean and press). In addition, 1-RM squat (TP and TH) and bench-press strength (TP, TH, UP, UH) improved in the groups where these exercises were performed. However, the initial improvements in 1-RM strength for squat and bench press (T3) in the FLD training group demonstrated that alternative methods could be effective in mediating an adaptation. The FLD training adaptations were most likely mediated by neural and stretch-shortening cycle mechanisms and therefore show that a combination of force and power training using relatively light loads can be effective over the first 3 months of training. The key appears to be the activation of type II motor units which are known to be activated even during ballistic, lighter load, higher velocity exercises (10,11,27). Other physical performances (e.g., repetitive box lift) tested in this study could then be viewed as requiring a combination of program characteristics to mediate their improvements and therefore were not partitioned in their improvements to one particular program type. In general, strength and power training improvements over this 6-month study were most likely mediated by a combination of physiological adaptations in the neuromuscular system (e.g., reduced inhibition, increased myofibrillar protein accretion, etc.) (6,26,32,33).

To our knowledge, this study was the first investigation to directly examine upper-body resistance training and its impact on physical performance in women. The data from this investigation supported our hypothesis that upper-body training would have a dramatic impact on all performance tasks that had a strong upper-body component in their performance. Except for 1-RM strength performances in the squat and high pull exercises (TP and TH), significant improvements were observed in all other strength/power tests by both total- and upper-body resistance training groups. This was particularly dramatic in the military-relevant occupational tasks where no differences among the resistance training groups were observed after 6 months of training. For example, 1-RM box lift performance at T6 (≈38 kg) was similar among the upper- and total-body resistance training groups. In a study by Sharp et al. (28) examining the effects of resistance training on materials handling in men, it was found that bench press performance was correlated with such task performances. Our data showed a similar trend with moderate correlations between 1-RM box lift and the 1-RM bench press (r = 0.58) ($P < 0.05$) as well as bench throw power (r = 0.60) ($P < 0.05$). In addition, the repetitive box lift performance also was correlated with 1-RM bench press (r = 0.56) ($P < 0.05$) and bench throw power results (r = 0.56) ($P < 0.05$). The reliance of the performance of such tasks on upper-body strength and power, and the apparent less significant contribution of total-body training, may be due to the biomechanical aspects of these tasks. The box lift tasks had a significant horizontal movement component in addition to the expected vertical movement vector. Specifically, in the final movement phase of the box lift tests, it was essential that the box be rapidly pushed outward and upward onto the platform landing. Because this horizontal movement phase also required the development of high force and power contributions from the upper-body, improvements in the box lift performances were largely dependent upon upper body adaptations.

In the repetitive box lift testing, it was interesting to observe the greatest performance gains were achieved during the first 3 months of training (Δs of ~20 to 25 reps from T0 to T3 vs Δs of ~10 reps from T3 to T6). Due to the fact that the majority of alterations take place in the acid-base system over the first 8 wk of high-intensity training (30), it appears plausible that continued improvements in strength/power alone could not mediate further improvement in repetitive box lift performance. Higher repetition protocols (>30 reps) may be needed in future programs to better address the dramatic local muscular endurance component of this task (2). In addition, the aerobic component of the conditioning program may also have contributed to improvements observed in the repetitive box lift performance (r = −0.54 with 2-mile run) ($P < 0.05$). Gains specific to such physiological components resulting from a "combination" of different exercise modes (i.e., resistance and aerobic training) may help in the physiological transfer to enhanced performance in such occupational tasks. This interaction of exercise stimuli contributing to enhanced physical performance was further supported by the moderate but significant improvement in the repetitive box lift performance observed in both the FLD and AER training groups by the end of the 6-month training period.

Load carriage was improved similarly after upper- and total-body strength training. Aerobic training alone did not improve 2-mile loaded-run performance, indicating that different from the repetitive box lift, a combination of strength/power and aerobic endurance was vital for improvement in this type of task. These data support the similar findings in men. Kraemer et al. (17) had previously demonstrated that upper-body training alone contributed to improved 2-mile loaded run performance but aerobic training alone did not. It is possible that enhanced load carriage may be due to improved postural support from stronger upper-body musculature, which thereby improves the mechanics of loaded locomotion. Interestingly, although such load carriage can be specifically used as a training tool in a conditioning program (12), our data show that performance can also be enhanced without such direct training and practice. This may help in potentially reducing the incidence of overuse injuries when directly using this task during training. Improvement in the load carriage task observed in the FLD group is again an interesting finding most likely related to the combined upper-body strengthening and the plyometric (stretch-shortening cycle adaptations) component for the lower-body training protocols (e.g., bounds and jumps) (16).

After 6 months of training, all resistance trained women in this study completed the push-ups, sit-ups, and 2-mile run tests at levels sufficient to successfully pass the U.S. Army Physical Fitness test although this was not true for the field and aerobic groups. Six months of resistance training in women also diminished the previous gender differences in push-up, sit-up, and 2-mile run performances as compared with the men. Furthermore, by the end of training, women's sit-up performance exceeded that of men. As with men, resistance training combined with aerobic endurance training provides an adequate exercise stimuli in women to address the fitness testing requirements of the U.S. Army (17).

A combined endurance and strength/power conditioning program can provide an effective intervention to reduce the "gender gap" in physical performances (see Figs. 4 and 5). Although not all performance differences between men and women can be completely eliminated with a 6-month training program (i.e., 1-RM strength), dramatic reductions can be observed. Most impressive to industrial and military operational environments were the impact of training on repetitive box lift and 2-mile loaded run tasks, which were raised to a level equal to the male norm. Also interesting, at T-6 the 1-RM squat relative to fat-free mass (1-RM squat (kg)/FFM (kg)) was not significantly different among the MEN (1.54 ± 0.36) and the total-body training groups [TP (1.49 ± 0.18) and TH (1.44 ± 0.29)], thus supporting prior studies where differences are eliminated between men and women for relative lower-body strength (37). Thus, limiting factors in performance gains appear to be the lower total muscle mass and strength of the upper-body as demonstrated by the lower fat-free mass in women and the small gains in 1-RM bench-press strength (3). Prior studies have shown that women have smaller muscle cross-sectional areas (due to smaller Type II fibers) and different muscle fiber type distributions as compared with men (1,34,35).

In general, the greatest improvements on the gender differences were seen in endurance capabilities both with aerobic performances and in local muscular endurance. This was especially true for the sit-ups, push ups, repetitive box lift, and 2-mile loaded run improvements. The mechanisms that mediate these responses are speculative but may be related to the preferential force production enhancement of the slow motor units with the combined training (e.g., aerobic plus resistance training) (32). Training may have enhanced overall muscle fiber size, allowing more force production without limiting the ability for repetitive force production capabilities in these slow twitch muscle fibers (35). Reliance upon a strategy for enhanced cross-sectional areas of all fibers with resistance training (32,35), a compatible aerobic training program (not too high of intensity and volume) (19), and improvement in neural mechanisms (26) could all have contributed to the optimization of such repetitive physical performances in women. However, maximal muscle strength may depend upon a more limited strategy for available high threshold motor units in women (26,35).

Despite a lack of clear separation in 1-RM strength performance gains between the different training designs, the significant group differences after 6 months of training (T6) may provide some insight into which training program designs elicited the greatest strength, power, and endurance adaptations. Specifically, the group differences in 1-RM bench press (TP, TH, UP, UH > AER; and TP > FLD), high pull (TP > all), squat jump power (TP > AER), and bench throw power (TP, UP > AER) demonstrated that, after only 6 months, the strength/power training programs resulted in significantly greater performances as compared to other training programs. Strength/hypertrophy training, on the other hand, resulted in significantly greater endurance performance as compared with other training programs (TH > UP, FLD, AER). Thus from our data, future programs for optimal enhancement of women's physical performance capacities would reflect a hybrid of the programs studied in this investigation. However, it is possible that the advanced training designs used in this investigation (i.e., periodization of training, repetition maximum training zones with progression, and direct supervision) elicited improvements in strength, power, and endurance at near optimal rates leaving only very small windows (if any) for greater or faster improvements in untrained women (8,9,23).

In summary, this investigation demonstrated that 6 months of periodized, resistance training significantly diminished the initial gender differences in physical performance capabilities including military relevant occupational tasks. It also demonstrated the importance of upper-body training in women. Also interesting, this study demonstrated that a FLD conditioning program was effective for moderate gains in physical performance. However, caution is to be taken as plateaus in performance typically occurred within 3 months of field training. Thus, future study should examine the efficacy of FLD training for maintaining strength adaptations in previously trained women (or men). Furthermore, aerobic training alone provided improvements in distance running performance but also made an interesting contribution to the improvement of the repetitive box lift task, most likely via acid-base adaptations. Finally, within the context of women's health, resistance training appears to be a vital component for physical performance enhancement and optimizing a woman's functional capacity in the demanding work environment of the 21st century.

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