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ABSTRACT

Purpose: This investigation sought to determine the most predictive measures of performance on a repetitive box lifting task (RBLT) and load bearing task (LBT) among 123 women (aged 23±4 years, height 165±7 cm, body mass 64±10 kg).

Methods: To determine the relationship of various predictors to performance on the RBLT and LBT, multiple regression analysis was conducted on body mass, height, leg cross-sectional area, upper and lower body muscular strength, lower body explosive power, upper and lower body local muscular endurance, and aerobic capacity.

Results: The mean±SD (range) number of repetitions for the RBLT was 86±23 (20-159). The mean±SD (range) time to complete the LBT was 2,054±340 seconds (1,307-3,447). The following equations were generated: RBLT (number of repetitions)=57.4+0.2(peak jump power)+0.4(number of pushups in 2 minutes)+0.15(number of repetitions during the squat endurance test)+1.39(one repetition maximal strength boxlift (kg))–0.04(2-mile run time (2MR) in seconds), R=0.81; standard error of the estimate (SEE)=14; LBT (in seconds)=1,831–4.28(number of repetitions during the squat endurance test)+0.95(2MR in seconds)–13.4(body mass), R=0.73; SEE=232.

Conclusions: We found that the 2MR and squat endurance test were significant predictive factors for performance on both load carriage tasks. These data also imply that women's performance in combat-related tasks can be improved with training that targets muscular strength, power, and local muscular endurance in addition to aerobic capacity.

Due to recent changes in Department of Defense policy, women in the military will have more opportunities to serve in combat arms military occupational specialties (MOS). These new opportunities will bring new challenges, including the ability to carry heavy loads over long distances in combat situations. Historically, the ability to lift and carry has been an important contributor to success in military combat operations.[1,2] As modern warfare incorporates increasingly heavier external loads, load carriage capability has gained recognition as an essential physical attribute in warfare.[3-5] Specifically, "fighting" loads average 29 kg, "approach" loads average 46 kg, and "emergency approach" loads average 60 kg.[1,2,6] These heavy loads often exceed the limits recommended by Army doctrine[1,6] and may partially explain why musculoskeletal injuries now comprise the largest proportion of all injuries.[7-10] Thus, as women enter new combat roles, it is necessary to determine which physical abilities are most closely related to performance on load carriage tasks. With this knowledge, load carriage-specific training interventions can be developed and implemented.[7,11,12]

The components of physical fitness that contribute the most to successful load carriage performance in women have been previously examined and are a growing area of research.[3,13-16] Load carriage is a frequent physical demand, particularly in deployed environments. Thus, a stronger Soldier could be expected to perform better on load carriage tasks and demonstrate greater resilience to the inherent injury risks these tasks present.[7,17,18] To that end, Kraemer et al,[16,19] Harman et al,[20] and Hendrickson et al[21] have shown that strength improvement, particularly in the upper body, has a profound impact on women's physical performance in military-specific tasks (ie, load carriage). Nevertheless, since loads are often carried over great distances and with considerable speed, high aerobic capacity is a common trait in Soldiers who successfully perform long distance load carriages.[2,3,12,21,22]

The prevalence of acute and overuse injuries to the spine and lower body[3,7,18,23-27] during military duties necessitates general physical preparedness and an emphasis on both strength and endurance capacity.[16,21] A Soldier's performance on military-relevant load carriage tasks may provide insight into his or her current state of physical preparation. Furthermore, due to the physically demanding nature of these tasks, directly addressing them in training programs may help resolve existing deficiencies. This is of paramount importance when load carriage and repetitive lifting tasks are performed in theatre under less than ideal conditions (ie, extreme fatigue, dehydration, extended combat operations), which contribute to increased injury likelihood and incidence.[10,28-30] A well-designed training program that emphasizes both resistance exercise and traditional cardiovascular training may not only improve Soldier performance, but also help prevent common overuse injuries that occur during load carriage tasks.

To better understand the physical demands of load carriage in women, we must evaluate the relationship of military-relevant tasks with various characteristics of physical fitness. Such data would not only help to characterize the physical requirements of these tasks but would also provide valuable information on the physical training required to enable female Soldiers to successfully perform the duties of combat MOSs. The purpose of this investigation was to identify the physical fitness components that most strongly predicted women's performance in 2 military-relevant occupational tasks. These tasks utilized loads and conditions that reflect limits prescribed by Army doctrine for approach marches,[1,2] Soldier testing and training, and previous experimental work.[12,19,20,31,32] These tasks included a repetitive box lifting task and an endurance-based, load bearing task. The knowledge obtained during this investigation could assist in the development of training strategies that, with time and further refinement, would allow for improved Soldier productivity, resilience, and injury rates.

MATERIALS AND METHODS

The study participants were 123 untrained civilian women (mean±SD: aged 23±4 years; height 165±7 cm; body mass 64±10 kg). Each subject was briefed on the risks and benefits of the investigation, and each signed an institutionally approved, informed consent document prior to her participation. Each subject was medically screened by a physician to eliminate any medical concerns or pathologies that may have compromised the subject's participation or confounded the results. This sample population of healthy women with no previous history of resistance training demonstrated a wide range of fitness capabilities, such that might be representative of a typical cohort of women entering into military service.[33,34] The factors used to predict task performance in this study were body mass, height, magnetic resonance imaging (MRI)-assessed thigh muscle cross-sectional area, one repetition maximal strength in the bench press, back squat, high pull and the box lift, pushup muscular endurance, explosive jump power, squat endurance, and 2-mile run time. All predictors and load carriage tasks had been previously shown to possess test-retest reliability correlations $R \geq 0.95$.[19]

Performance Predictors

1. Thigh muscle cross-sectional area (TMCSA). The TMCSA was assessed for the dominant leg using an MRI 0.5 Tesla super conduction magnet (Picker International Inc, Highland Heights, OH) with MR6B software. Tissue cross sectional area was obtained by displaying the images through a Maxitron displayer and Adobe program and using the MacIntosh version NIH 1.55.20A Image Analysis computer program (National Institutes of Health, Washington, DC).

2. One repetition maximal strength (1RM) measures. These strength measures consisted of the squat, bench press, high pull, and box lift and were assessed with the use of the Plyometric Power System (PPS) (Power Systems Inc, Knoxville, TN). The PPS was specially designed to accurately collect strength and power data and to safeguard against injury by using a braking system to prevent falls. A National Strength and Conditioning Association Certified Strength and Conditioning Specialist monitored all tests and ensured compliance with prescribed exercise techniques. For the 1RM squat, the subject was required to descend into a parallel squat position by flexing the knees and hips until the trochanteric head of the femur reached the same plane as the superior border of the patella.[35] For the 1RM bench press, the subject was required to lower the bar until it touched the chest, and lift the bar back to the straight-arm position.[35] For the 1RM high pull, the subject stood upright with arms extended at the sides of the body and the feet positioned so that the instep of each foot was directly under the bar (resting position). The subject then flexed her hips before performing a simultaneous "triple extension" (of the ankle, knee, and hips) with maximal power while pulling the bar, using trapezoid flexion and shoulder abduction, to the height of the medial clavicles (the finish position).[35] The 1RM box lift required the subject to lift a box from the floor to a height of 1.32 m (simulating the bed height of a military 5-ton cargo truck). Upon failing at an attempt on any of the 1RM tests, the subject was given a final attempt with a weight less than that used in the failed attempt, but greater than that of the highest successful attempt (adapted from Maud and Foster[35]).

3. Muscular endurance and aerobic capacity. The maximum number of pushups that a subject could perform correctly in 2 minutes was used to assess upper body muscular endurance. The minimum amount of

time in which a subject completed a 2-mile run was used to assess aerobic capacity. Both of these measures were tested according to guidelines and procedures provided in *Field Manual 21-20* (now obsolete, superseded by *Field Manual 7-22*[36])

4. Squat endurance test. The squat endurance test required the subjects to perform repetitive squatting with an absolute load of 45.36 kg placed on the PPS barbell system which was lifted over a specific distance of 0.36 m per repetition at a rate of 37.5 repetitions per minute (0.625 repetitions per second).[19] These specifications were employed to allow for an external power output of 100 watts during the test. The total number of repetitions that the subject performed was used for analysis.

5. Lower body explosive power. To assess lower body explosive power, subjects performed an explosive squat jump lift using the PPS interfaced with a computer for data acquisition. Each subject's previously determined 1RM squat load was used to calculate her 30% of 1RM intensity for use in the squat jump test. The squat jump required the subject to perform a parallel squat and, upon reaching the bottom position of the lift, to explosively extend the hips and knees, thus accelerating the barbell mass upward with maximum power.[19,37]

Military-relevant Occupational Tasks

1. Repetitive box lift task (RBLT). The RBLT required the repetitive lifting of two 20.45 kg metal boxes placed on 2 platforms 1.32 m high (again, to simulate the height of a 5-ton military cargo truck) and 2.4 m apart. The subject moved at a volitional pace between one platform and the other to lift the box from its position adjacent to the platform to the top of that platform. The purpose of the test was to measure the subject's ability to lift as many boxes as possible in 10 minutes; performance was measured by the total number of boxes lifted (adapted from Harman et al[38] and Knapik[39]).

2. Load bearing task (LBT). The LBT required the subjects to carry a 34.1 kg backpack (termed rucksack) a distance of 2 miles on an all-weather 400 m track. The rucksack was constructed of an external frame with an attached backpack in which the load was properly positioned. Upon command, the subjects moved as fast as they could to cover the 2-mile distance. The performance was measured in seconds.[19]

Statistical Analyses

Values are reported as means±SD. Prior to all statistical runs, the data were confirmed to have met the statistical assumptions for linear statistics. Simple and stepwise multiple regression analyses were used to determine relationships between and among variables and to determine the proportion of variance explained by specific variables of interest that entered into the respective regression equations for the RBLT and the LBT. In this study, significance was defined as $P \leq .05$.

RESULTS

Table 1 lists the descriptive data for the various tests and with the 25th, 50th, and 75th percentiles presented for all variables. These variables were selected because they represent a broad spectrum of physical fitness components that influence military task performance. We attempted to select tests that assessed upper and lower body muscular strength, power, and endurance as well as aerobic capacity. Depending on the variable (as shown in Table 1), data was collected for 113 to 123 study participants. For some variables (eg, pushups and squat endurance) some subjects failed to complete a successful repetition, thus demonstrating a high discriminating ability for these tests.

Table 2 displays the correlational matrix among all variables. All of the independent variables were significantly correlated with the 2 dependent variables (RBLT and LBT). The 2-mile run time yielded the highest

Table 1. Descriptive Data for the Various Tests. The variables were selected because they represent a broad spectrum of physical fitness components that influence military task performance.

Variable	n	Mean±SD (range)	25th Percentile	50th Percentile	75th Percentile
Height (cm)	122	166±7 (145-184)	162	166	169
Weight (kg)	123	64±10 (43-106)	57	62	70
TMCSA (cm^2)	122	122±17 (89-183)	111	120	132
Bench press (kg)	123	32±7 (17-58)	26	31	35
Squat (kg)	123	52±12 (17-88)	44	52	58
High pull (kg)	121	33±6 (15-54)	29	32	36
Maximal box lift (kg)	121	30±5 (21-48)	27	30	33
Pushups (no. reps)	120	20±13 (0-57)	10	17	28
Squat endurance (no. reps)	116	19±14 (0-95)	8	16	24
Jump power (watts)	116	1,623±323 (875-2,868)	1,390	1,587	1,797
Two mile run (seconds)	120	1,213±231 (830-2,040)	1,358	1,191	1,043
Rucksack run (seconds)	113	2,054±337 (1,307-3,447)	2,267	2,025	1,850
Repetitive box lift (reps)	113	86±23 (20-159)	69	85	104

Notes: n=number of participants from which data was collected; TMCSA indicates thigh muscle cross-sectional area; reps indicates repetitions.

Table 2. Matrix of Correlation Among the Variables.

	BP	BL	TCSA	HP	HT	JP	PU	SE	SQ	2MR	BM	RBLT	LBT
BP	1.00*	0.58*	0.50*	0.71*	0.09	0.50*	0.48*	0.48*	0.57*	-0.28*	0.24*	0.56*	-0.48*
BL	0.58*	1.00*	0.53*	0.62*	0.46*	0.66*	0.10	0.43*	0.58*	-0.03	0.53*	0.54*	-0.37*
TCSA	0.50*	0.53*	1.00*	0.60*	0.24*	0.74*	-0.03	0.50*	0.61*	0.00	0.60*	0.41*	-0.31*
HP	0.71*	0.62*	0.61*	1.00*	0.20*	0.66*	0.20*	0.52*	0.58*	-0.18*	0.32*	0.52*	-0.42*
HT	0.09	0.46*	0.29*	0.20*	1.00*	0.44*	-0.35*	0.22*	0.04	0.01	0.54*	0.22*	-0.27*
JP	0.50*	0.66*	0.74*	0.66*	0.44*	1.00*	-0.10	0.59*	0.64*	0.00	0.67*	0.47*	-0.35*
PU	0.48*	0.10	-0.03	0.20*	-0.35*	-0.01	1.00*	0.24*	0.28*	-0.52*	-0.39*	0.45*	0.26*
SE	0.48*	0.43*	0.50*	0.52*	0.22*	0.59*	0.24*	1.00*	0.59*	-0.32*	0.17	0.55*	-0.46*
SQ	0.57*	0.58*	0.61*	0.58*	0.04	0.69*	0.28*	0.59*	1.00*	-0.16	0.26*	0.48*	-0.27*
2MR	-0.28*	-0.03	0.00	-0.18*	0.01	0.00	-0.52*	-0.32*	-0.16*	1.00*	0.41*	-0.54*	0.60*
BM	0.24*	0.53*	0.60*	0.32*	0.54*	0.67*	-0.39*	0.17	0.26*	0.41*	1.00*	0.19*	-0.19*
RBLT	0.56*	0.54*	0.41*	0.52*	0.20*	0.47*	0.45*	0.55*	0.48*	-0.54*	0.19*	1.00*	-0.61*
LBT	-0.48*	-0.37*	-0.31*	-0.42*	-0.27*	-0.35*	-0.26*	-0.46*	-0.27*	0.60*	-0.19*	-0.61*	1.00*

*$P \leq .05$

Key

BP – 1RM bench press (kg)
BL – 1RM box lift (kg)
TCSA – thigh cross-sectional area (cm^2)
HP – 1RM high pull (kg)
HT – height (cm)
JP – jump power (W)
PU – pushups
SE – squat endurance
SQ – 1RM squat (kg)
2MR – 2 mile run time
BM – body mass (kg)
RBL – repetitive box lift
LBT – load bearing task (2-mile rucksack carry)

Table 3. Regression equations for repetitive box lifting tasks (RBLT) and load bearing task (LBT).

Variable	Regression Equation	R	R^2	SEE
RBLT (reps)	57.4+0.2(JP)+0.4(PU)+0.15(SE)+1.39(BL)−0.04(2MR)	0.81	0.65	14
LBT (seconds)	1831−4.28(SE)+0.95(2MR)−13.4(BM)	0.73	0.53	232

Key

reps – repetitions
JP – jump power
PU – pushups
SE – squat endurance
BL – 1RM box lift
2MR – 2 mile run time
BM – body mass (kg)

correlation overall (r=-0.54 for the RBLT and 0.60 for the LBT). Other factors also contributed to these task performances, as only about 36% of the shared variance was explained. It is interesting to note that the test battery used was diverse and represented different physical requirements of the neuromuscular system as noted by the low to moderate relationships for multicollinearity of the tests performed.

Table 3 provides the regression equations for the RBLT and the LBT. For the RBLT; the explosive jump power, pushups, squat endurance test, 1RM box lift, and 2-mile run time entered into the equation. For the LBT; the squat endurance test, 2-mile run time, and body mass entered into the equation.

The final regression equations explained approximately 65% of the variance for the RBLT and 53% of the variance for the LBT. The standard errors of estimates were 14 repetitions for the RBLT and 232 seconds for the LBT. Interestingly, the squat endurance test and timed 2-mile run contributed significantly to both regression equations. Our results show that, depending on the physical demands of the task, both aerobic capacity and local muscular endurance can contribute significantly to task performance.

COMMENT

Research has consistently shown that increased strength contributes to significant improvements in military-specific task performance.[3,16,19,21] Previous studies have demonstrated that stronger, more muscular individuals perform load carriage and repetitive lifting tasks more efficiently and with indications of lower stress to the musculoskeletal system.[3,12,19,20] The results of the present investigation support the argument that upper and lower body strength, power, and local muscular endurance play important roles in load carriage task performance in women. Currently, military physical fitness training prioritizes traditional cardiovascular training. Our findings also support the importance of aerobic capacity, as higher aerobic capacity was associated with decreased

LBT time, while lower aerobic capacity was associated with decreased RBLT volume. It appears that training strategies for military populations must include both resistance and traditional cardiovascular training.

Our findings also reflect the importance of training specificity. For example, the 1RM box lift factored strongly into performance on the RBLT. This is not surprising if we consider that individuals who are able to lift heavier loads (eg, 1RM box lift) will likely perform better on a related task such as the RBLT. Furthermore, lower body power (jump squat) and local muscular endurance (pushups and squat endurance) could be expected to contribute positively to a repetitive box-lifting task, which would appear to require these qualities. Performance on the LBT also appeared to reflect the task's specific physical attributes most strongly. For instance, lower aerobic capacity, reflected in higher 2-mile run times, corresponded with higher LBT times, while increased body mass and lower body muscular endurance were associated with improved LBT times. Nevertheless, performance on both tasks benefitted from higher aerobic capacity and local muscular endurance, thus illustrating the transferability of more nonspecific exercise adaptations.

The principle of specificity dictates that training mirror the specific physical requirements of the activity.[14,40] Therefore, to the extent possible, training programs for Soldiers should include physical tasks that are similar to those required by the MOS or duty assignment. Current training recommendations for load carriage include performing specific load carriage tasks with progressive loading and duration once per week, in addition to resistance training and aerobic conditioning.[22] The selected occupational tasks (LBT and RBLT) were deemed highly relevant—they are either regularly performed or used in training.[1,2,31,41] Our findings also highlight the importance of upper body strength in women, as the 1RM box lift and pushup results were significant predictors of RBLT performance.[19,39]

It is important to note that the 2 tasks evaluated in this study require many performance strategies, physiological systems, psychological demands, and biomechanical techniques. Therefore, it might be expected that the physical components measured in this study do not completely explain performance on these 2 tasks. Psychological factors such as motivation may also explain some of the results. In addition, the use of nonmilitary volunteers might have produced findings that would differ from those of enlisted women although we specifically chose college-aged women of varying fitness and anthropometrics in order to simulate a plausible enlistment cohort. Thus, other tests and/or factors (eg, psychological, inherent differences between enlisted and civilian volunteers) may need to be explored to better predict performance in untrained women. Finally, any laboratory test, however similar to those tasks carried out in combat, should not be expected to possess complete predictive accuracy as it relates to performance in theatre. A true evaluation of performance requires a multifactorial assessment encompassing both physical and psychological motivating factors in combat situations.

RELEVANCE TO PERFORMANCE TRIAD

Muscular endurance, strength, power, aerobic capacity, and task-specific ability are all factors that influence an individual's performance on military load carriage and repetitive lifting tasks such as those evaluated here. These data are important because it is necessary to know what components of physical fitness contribute to military task performance so adequate training programs can be designed. The primary value of this study is that it reports the relationships of various physical fitness components to military task performance in women. Prior research has demonstrated that load carriage can result in overuse injuries, particularly to the spine and lower extremities. Regardless of the injury risk, load carriage is an integral part of soldiering, and the external loads that Soldiers are required to carry has increased in recent years, despite improvements in load carriage equipment.

As the military continues to place heavy demands on Soldiers and expands combat arms MOS opportunities to women, it is paramount that training programs include heavy periodized resistance training to improve lower and upper body power, strength, and local muscular endurance, in addition to traditional cardiovascular training. Moreover, the present investigation highlights the importance of training specificity. To the extent possible, training should reflect occupation-specific tasks such as load carriage.

REFERENCES

1. Dean C. *The Modern Warrior's Combat Load. Dismounted Operations in Afghanistan, April-May 2003.* Fort Leavenworth, Kansas: US Army Center for Army Lessons Learned; 2004.
2. Dijk V. Chapter 3–Common Military Task: Marching. In: *RTO-TR-HFM-080: Optimizing Operational Physical Fitness*. Final Report of Task Group 019. Brussels, Belgium: NATO Research and Technology Organization; 2009. Available at: http://www.cso.nato.int/pubs/rdp.asp?RDP=RTO-TR-HFM-080. Accessed September 4, 2013.

3. Knapik JJ, Harman EA, Steelman RA, Graham BS. A systematic review of the effects of physical training on load carriage performance. *J Strength Cond Res.* 2012;26(2):585-597.
4. Interceptor body armor [internet]. Available at: http://www.globalsecurity.org/military/systems/ground/interceptor.htm. Accessed September 4, 2013.
5. Konitzer LN, Fargo MV, Brininger TL, Lim Reed M. Association between back, neck, and upper extremity musculoskeletal pain and the individual body armor. *J Hand Ther.* 2008;21(2):143-148.
6. Nindl BC, Castellani JW, Warr BJ, et al. Physiological employment standards III: physiological challenges and consequences encountered during international military deployments. *Eur J Appl Physiol.* 2013 [epub ahead of print].
7. Knapik JJ, Reynolds KL, Harman E. Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Mil Med.* 2004;169(1):45-56.
8. Roy TC. Diagnoses and mechanisms of musculoskeletal injuries in an infantry brigade combat team deployed to Afghanistan evaluated by the brigade physical therapist. *Mil Med.* 2011;176(8):903-908.
9. Roy TC, Knapik JJ, Ritland BM, Murphy N, Sharp MA. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med.* 2012;83(11):1060-1066.
10. Roy TC, Ritland BM, Knapik JJ, Sharp MA. Lifting tasks are associated with injuries during the early portion of a deployment to Afghanistan. *Mil Med.* 2012;177(6):716-722.
11. Knapik J, Harman E, Reynolds K. Load carriage using packs: a review of physiological, biomechanical and medical aspects. *Appl Ergon.* 1996;27(3):207-216.
12. Pandorf C, Harman EA, Frykman PN, Patton JF, Mello RP, Nindl BC. Correlates of load carriage and obstacle course performance among women. *Work.* 2002;18(2):179-189.
13. Kraemer WJ, Fleck SJ, Deschenes MR. *Exercise Physiology: Integrating Theory and Application*. Philadelphia, PA: Lippincott Williams & Wilkins; 2012.
14. Kraemer WJ, Fleck SJ, Dziados JE, et al. Changes in hormonal concentrations after different heavy-resistance exercise protocols in women. *J Appl Physiol.* 1993;75(2):594-604.
15. Kraemer WJ, Nindl BC, Ratamess NA, et al. Changes in muscle hypertrophy in women with periodized resistance training. *Med Sci Sports Exerc.* 2004;36(4):697-708.
16. Kraemer WJ, Vescovi JD, Volek JS, et al. Effects of concurrent resistance and aerobic training on load-bearing performance and the Army physical fitness test. *Mil Med.* 2004;169(12):994-999.
17. Holewijn M. Physiological strain due to load carrying. *Eur J Appl Physiol.* 1990;61(3-4):237-245.
18. Lafiandra M, Harman E. The distribution of forces between the upper and lower back during load carriage. *Med Sci Sports Exerc.* 2004;36(3):460-467.
19. Kraemer WJ, Mazzetti SA, Nindl BC, et al. Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc.* 2001;33(6):1011-1025.
20. Harman E, Frykman P, Palmer C, Lammi E, Reynolds K, Backus V. *Report No. T98-1: Effects of a Specifically Designed Physical Conditioning Program on the Load Carriage and Lifting Performance of Female Soldiers.* Natick, MA: US Army Research Institute of Environmental Medicine; 1997. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA333437. Accessed September 4, 2013.
21. Hendrickson NR, Sharp MA, Alemany JA, et al. Combined resistance and endurance training improves physical capacity and performance on tactical occupational tasks. *Eur J Appl Physiol.* 2010;109(6):1197-1208.
22. Henning PC. Physical training to optimize load carriage in the tactical operator [internet]. National Strength and Conditioning Association; 2013. Available at: http://www.nsca-lift.org/Education/Articles/Hot-Topic-Physical-Training-to-Optimize-Load-Carriage/. Accessed September 4, 2013.
23. Birrell SA, Hooper RH, Haslam RA. The effect of military load carriage on ground reaction forces. *Gait Posture.* 2007;26(4):611-614.
24. Knapik JJ, Darakjy S, Jones SB, et al. *Epidemiological Report No. 12-HF-05SR-05: Injuries and Physical Fitness Before and After Deployment by the 10th Mountain Division to Afghanistan for Operation Enduring Freedom.* Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine; 2007. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA496351. Accessed September 4, 2013.

25. Knapik JJ, Rieger W, Palkoska F, Van Camp S, Darakjy S. United States Army physical readiness training: rationale and evaluation of the physical training doctrine. *J Strength Cond Res.* 2009;23(4):1353-1362.

26. Rodriguez-Soto AE, Jaworski R, Jensen A, et al. Effect of load carriage on lumbar spine kinematics. *Spine (Phila Pa 1976).* 2013;38(13):E783-E791.

27. Sell TC, Pederson JJ, Abt JP, et al. The addition of body armor diminishes dynamic postural stability in military soldiers. *Mil Med.* 2013;178(1):76-81.

28. Lester ME, Knapik JJ, Catrambone D, et al. Effect of a 13-month deployment to Iraq on physical fitness and body composition. *Mil Med.* 2010;175(6):417-423.

29. Nindl BC, Barnes BR, Alemany JA, Frykman PN, Shippee RL, Friedl KE. Physiological consequences of U.S. Army Ranger training. *Med Sci Sports Exerc.* 2007;39(8):1380-1387.

30. Reynolds K, Cosio-Lima L, Bovill M, Tharion W, Williams J, Hodges T. A comparison of injuries, limited-duty days, and injury risk factors in infantry, artillery, construction engineers, and special forces soldiers. *Mil Med.* 2009;174(7):702-708.

31. Kraemer WJ, Vogel JA, Patton JF, Dziados JE, Reynolds KL. *Report 30-87: The Effects of Various Physical Training Programs on Short Duration, High Intensity Load Bearing Performance and the Army Physical Fitness Test.* Technical. Natick, MA: US Army Research Institute of Environmental Medicine; 1987. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA185473. Accessed September 4, 2013.

32. Pandorf CE, Nindl BC, Montain SJ, et al. Reliability assessment of two militarily relevant occupational physical performance tests. *Can J Appl Physiol.* 2003;28(1):27-37.

33. Sharp MA, Patton JF, Knapik JJ, et al. Comparison of the physical fitness of men and women entering the U.S. Army: 1978-1998. *Med Sci Sports Exerc.* 2002;34(2):356-363.

34. Knapik JJ, Sharp MA, Darakjy S, Jones SB, Hauret KG, Jones BH. Temporal changes in the physical fitness of US Army recruits. *Sports Med.* 2006;36(7):613-634.

35. Maud PJ, Foster C, eds. *Physiological Assessment of Human Fitness.* 2nd ed. Champaign, IL: Human Kinetics; 2006.

36. *Field Manual 7-22: Army Physical Readiness Training.* Washington, DC: US Dept of the Army; October 2012. Available at: http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/fm7_22.pdf. Accessed September 4, 2013.

37. Wilson GJ, Newton RU, Murphy AJ, Humphries BJ. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc.* 1993;25(11):1279-1286.

38. Harman EA, Frykman PN, Clagett ER, Kraemer WJ. Intra-abdominal and intra-thoracic pressures during lifting and jumping. *Med Sci Sports Exerc.* 1988;20(2):195-201.

39. Knapik JJ. The influence of physical fitness training on the manual material handling capability of women. *Appl Ergon.* 1997;28(5-6):339-345.

40. Spiering BA, Kraemer WJ, Anderson JM, et al. Resistance exercise biology: manipulation of resistance exercise program variables determines the responses of cellular and molecular signaling pathways. *Sports Med.* 2008;38(7):527-540.

41. Knapik J, Johnson R, Ang P, et al. *Report No. T14-93: Road March Performance of Special Operations Soldiers Carrying Various Loads and Load Distributions.* Natick, MA: US Army Research Institute of Environmental Medicine; 1993.

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