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Prediction of Simulated Battlefield Physical Performance from Field-Expedient Tests

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ABSTRACT Predictive models of battlefield physical performance can benefit the military. To develop models, 32 physically trained men (mean ± SD: 28.0 ± 4.7 years, 82.1 ± 11.3 kg, 176.3 ± 7.5 cm) underwent (1) anthropometric measures: height and body mass; (2) fitness tests: push-ups, sit-ups, 3.2-km run, vertical jump, horizontal jump; (3) simulated battlefield physical performance in fighting load: five 30-m sprints prone to prone, 400-m run, obstacle course, and casualty recovery. Although greater body mass was positively associated with better casualty recovery performance, it showed trends toward poorer performance on all the other fitness and military performance tests. Regression equations well predicted the simulated battlefield performance from the anthropometric measures and physical fitness tests (r = 0.77–0.82). The vertical jump entered all four prediction equations and the horizontal jump entered one of them. The equations, using input from easy to administer tests, effectively predict simulated battlefield physical performance.

INTRODUCTION

The development of predictive models of battlefield physical performance can be of significant value to the military by (1) providing advance knowledge to military leaders about the capabilities of their troops, thereby enhancing military decision-making, (2) aiding in the selection of personnel for units expected to face demanding physical challenges, (3) providing a focus for physical training by identifying what physical abilities are essential to battlefield performance, and (4) providing an important tool for the evaluation of military physical training programs.

The ability to carry heavy loads quickly is one militarily-relevant physical ability that has been the subject of various prediction efforts. Linear regression models have been developed to predict load carriage performance from physical fitness test scores and body composition measures. Williams and Rayson[1] tested 84 British soldiers carrying 15 kg and 25 kg and derived statistically significant regression models to predict 3.2-km load carriage time (R^2 = 0.06–0.80). In a study designed to provide information for setting British Army selection standards, Rayson, Holliman, and Belyavin[2] timed different groups of men and women (totaling 340 men and 75 women from various British Army specialties) as they carried 10- to 25-kg loads. Different equations to predict load carriage times were developed for each of the groups tested with r = 0.61–0.87. The input variables selected for the equations among the groups tested included VO_{2max}, upright isometric pull force, static arm flexion endurance, body fat, body weight, and gender. A follow-up study[3] on 214 male and 112 female soldiers determined that the equations could be recommended for evaluation of recruits after 9 weeks of training. Pandorf et al.[4] determined that time to cover 3.2 km on foot with loads of 14 kg, 27 kg, and 41 kg were well-predicted by absolute VO_{2max} and 3.2-km unloaded run time. Based on tests of 113 women volunteers, Kraemer et al.[5] developed a linear regression equation to predict 3.2-km 34-kg load carriage time (r = 0.73) from 3.2-km unloaded run time, 45-kg barbell squat endurance, and body mass.

Lifting strength, which is essential to many military jobs, has been modeled as well. Williams and Rayson[6] derived statistically significant linear regression models that predicted change in maximal box-lift capability from changes in strength test scores and body composition. Rayson, Holliman, and Belyavin,[2] in their British Army study reported that single lift maximum weight could be successfully predicted by isometric and dynamic muscle strength scores and fat-free body mass (r = 0.63–0.77). With gender included as a variable, r improved to 0.94. An evaluation study of the equations[3] found them valid for prediction of lifting ability.

Attempts at modeling the ability to carry loads in the hands have been made as well. Kraemer[5] produced an equation to predict the number of times women could carry and lift 20-kg boxes in 10 minutes (r = 0.81) from five other physical test scores. The length of time subjects could carry a stretcher with an 82-kg manikin was effectively predicted (r^2 = 0.99) by a linear regression equation incorporating lean cross-sectional areas of the forearm and thigh, as well as the maximum number of push-ups performed.[7] Rayson, Holliman, and Belyavin[2] produced statistically significant prediction models for carrying and repetitive lifting, but both models had large errors in prediction.

Attempts have also been made to predict obstacle course performance. Bishop et al.[8] performed various anthropometric and physical ability tests, including skinfolds, upper and lower body aerobic and anaerobic power, muscular strength,

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and endurance. Lighter subjects performed better, and the best equation for obstacle course time was based on percent body fat, body mass, and Wingate-measured arm and leg maximum power relative to body mass ($r = 0.65$). The particular obstacle course appeared to put heavy emphasis on the upper body. Jette et al.[9] used the results from several laboratory tests to predict performance on a very long, 19-station obstacle course and found that VO_2max and strength scores were good predictors of performance. The length of the test appears to favor aerobic capacity.

Efforts at predicting other aspects of military performance have also been made. In one study, over 4,000 candidates in the Special Forces Assessment and Selection program were tested to predict their success in the program. Score on the Army Physical Fitness Test (APFT) correlated weakly with success in the program ($r = 0.25$), while time for a backpack carry test correlated more strongly with success ($r = 0.49$).[10] The U.S. Navy examined the value of anthropometric measures and physical fitness tests (sit-and-reach, push-ups, curl-ups, pull-ups, long jump, 1.5-mile run, 3-mile run, 500-yard pool swim, and 1000 ocean swim) for predicting job performance of explosive ordnance disposal divers, as measured by a dive equipment carry, double scuba tank lift, 500-yard bay swim, and 100-yard rescue swim.[11] Body mass significantly predicted the scuba tank lift and the bay and rescue swim times. Height related significantly to the times for the equipment carry and bay swim. However, the general physical fitness test measures turned out to be poor predictors of job performance.

Few attempts have been made to predict, from easy to administer anthropometric measures and field-expedient physical fitness tests, the ability to perform the kinds of physical challenges soldiers can face right on the battlefield, such as running between points of cover, negotiating obstacles, and rescuing casualties. Thus, the purpose of this study was to determine whether field-expedient tests, which do not require a high degree of training or expensive equipment, could be used to predict simulated physically demanding battlefield performance. We hypothesized that the selected tests would provide adequate input for effective predictive equations.

METHODS

Subjects

We recruited 32 civilian males from 18 to 35 years of age, from varied educational and professional backgrounds, who met the U.S. Army weight-for-height induction standards. The means and SD of their age, body mass, and height were, respectively, 28.0 ± 4.7 years, 82.1 ± 11.3 kg, and 176.3 ± 7.5 cm. Their exercise history varied from sedentary to active, as is typical for an Army recruit population. The volunteers gave their informed consent, after which they underwent physical examinations to ensure they could safely perform very strenuous exercise testing and training. The investigators adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and we conducted the research in adherence with the provisions of 45 CFR Part 46. The Human Use Review Committee of the U.S. Army Research Institute of Environmental Medicine and the Human Subjects Research Review Board of the U.S. Army Medical Research and Materiel Command approved the study.

Procedures

We trained the volunteers for 8 weeks using military training methods to establish a baseline of military physical fitness, then tested them over 2 weeks using simple anthropometry, field-expedient physical fitness tests, and simulated battlefield physical performance tests described below. We used Pearson product moment correlation (r) to examine the associations between scores on the anthropometric measures, field-expedient physical fitness tests, and simulated battlefield physical performance tests. In addition, we used forward stepwise multiple linear regression to determine whether we could effectively predict simulated battlefield physical performance from scores on the field-expedient physical fitness tests and anthropometric measures.

Field-Expedient Physical Fitness Tests

For all of the following tests, the volunteers wore t-shirts, shorts, and running shoes.

U.S. APFT

The APFT is made up of three test components, administered to all soldiers twice per year, except if they are on medical waivers. Points for each test are awarded based on table values for gender and age, with a score of 60 of 100 passing for each test. Soldiers not passing the test may be dismissed from the Army after being given a limited time to improve. We administered the tests as specified in the Army physical fitness manual.[12] As per the manual, the tests were given in the following order, with a 10- to 20-minute rest in between.

Push-ups. The number of push-ups the volunteers could do in 2 minutes was recorded.

Sit-ups. The number of bent-leg sit-ups (hands behind the neck, feet held down) the volunteers could do in 2 minutes was observed.

3.2-km run. This test reflected the time the volunteer took to run 3.2 km (2 miles) at maximal speed on a level paved surface.

Jumping Tests

These tests consisted of the following.

Standing vertical jump. While standing with the feet flat on the floor, the volunteer reached up as high as possible with the right hand and displaced horizontal plastic fins on a Vertec jump meter (Sports Imports, Columbus, Ohio) that measured height to the nearest 1.3 cm (0.5 inch). The volunteer then jumped as high as possible, again displacing the highest fin possible on the Vertec with the right hand. Jump

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height was scored as the difference between the two readings. The volunteers were allowed to swing their arms and flex their knees before the jump, but not allowed to take any steps. Maximum vertical jump distance was taken as the best of three attempts.

Standing horizontal jump. Volunteers stood with toes at the starting line of a rubber jump mat marked with lines indicating distance from the start (M-F Athletic Co., Cranston, Rhode Island), and jumped as far as possible horizontally. The jump was scored as the distance between the starting line and portion of the body contacting the mat closest to the starting line. The volunteers were allowed to swing their arms and flex their knees before the jump, but not allowed to take any steps. Maximum horizontal distance was taken as the best of three attempts.

Anthropometric Measures

Height and body mass were measured to determine whether simple anthropometric variables would enhance the predictive value of the field-expedient physical fitness tests.

Tests of Simulated Battlefield Physical Performance

For all of the following tests, the volunteers wore the Army battle dress uniform— boots, Kevlar helmet, a military armored vest with protective ceramic plates, and a fighting vest with dummy ammunition—and carried a dummy M-16 rifle of authentic weight and shape. The mass of this ensemble, considered a standard infantry fighting load,[13] was approximately 18 kg, with minor variation due to size differences of clothing, boots, body armor, and helmet.

Timed 400-m run. This run was conducted on pavement and included two right angle turns, simulating a sprint across an urban battle site. The score was the time taken to complete the run.

Timed obstacle course. This simulated traversal of a battlefield strewn with obstacles. The volunteer had to: (1) leap over four successive 61-cm high hurdles, (2) run in a zigzag pattern around nine rubber cones arranged in an array 27-m long and 1.5-m wide, (3) crawl under a rectangular barrier 0.6-m high, 0.9-m wide, and 3.7-m long, (4) shimmy 3.7 m along a 6-cm diameter horizontal pipe, (5) climb over a 1.4-m high sheer wooden wall, (6) sprint 29 m, (7) climb onto a 1.55 high sheer-faced platform, and (8) run up two flights of stairs. The volunteers were familiarized with the course and given two practice runs before the timed runs, one without a load and one with the fighting load. To protect the volunteers, a hockey helmet was used instead of the Kevlar helmet in this event. The score was the time taken to run the entire course.

Timed 30-meter rushes. This test simulated the short rushes between points of cover that soldiers use to move on a battlefield. The volunteer started in a prone position on a mat. On verbal command, the volunteer got up, sprinted 30 m, and got prone on a second mat. After a timed 5-second pause, during which the volunteer pivoted in the prone position to face the first mat, another verbal command signaled the volunteer to run back to the first mat and get prone. The process continued until the volunteer had completed five 30-m rushes. The score was the time taken to complete the five rushes.

Simulated casualty rescue. This test simulated the rescue of an injured comrade on the battlefield. Upon verbal command, the volunteer ran 50 m to an 80-kg Survivor manikin (Dummies Unlimited, Pomona, California), took hold of a web handle on the upper-back portion of the manikin's military vest, and dragged the manikin 50 m back to the starting line.

RESULTS

The means and SDs for the scores on all of the tests administered are shown in Table I. Table II presents an intercorrelation matrix of the anthropometric and field-expedient physical fitness tests. The only significant ($p < 0.05$) correlations with body height were with body mass and sit-up repetitions, both of which increased with height. Body mass showed no significant correlations aside from its correlation with height. Yet, there were nonsignificant trends toward poorer performance on all of the physical fitness tests with increased body mass. The vertical jump was significantly correlated with the horizontal jump. Better performance on the horizontal jump significantly correlated with better 3.2-km run performance. The number of push-up and sit-up repetitions was significantly correlated, and both push-up and sit-up ability correlated significantly and well with 3.2-km running ability.

Table III shows the intercorrelations of the tests of simulated battlefield physical performance, all of which were positive, indicating that faster times on all of these tests were associated with faster times on all the others. Performance on both the 30-m rush and 400-m run tests were moderately to well associated with performance on all of the tests of simulated battlefield physical performance. However, the obstacle course and casualty rescue tests were not as effective overall military performance predictors because they correlated only weakly and nonsignificantly with each other.

Correlations of the anthropometric and field-expedient physical fitness test scores with scores on the tests of simulated battlefield physical performance are listed in Table IV. Height did not prove to be an effective predictor of simulated battlefield physical performance, with no significant correlations. Body mass showed stronger correlations; heavier body

TABLE I. Means and SD of all Tests ($n = 32$)

	Mean ± SD
Height (cm)	176.3 ± 7.5
Body mass (kg)	82.1 ± 11.3
Vertical jump (cm)	50.0 ± 7.4
Horizontal jump (cm)	219.9 ± 25.6
2-minute push-ups (*n*)	44.9 ± 10.8
2-minute sit-ups (*n*)	53.0 ± 11.7
2-mile run (s)	891.2 ± 105.3
Casualty drag (s)	43.1 ± 9.3
400-meter run (s)	83.9 ± 10.3
30-meter rushes (s)	59.3 ± 3.5
Obstacle course (s)	68.2 ± 12.3

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TABLE II. Intercorrelations of the Anthropometric and FIELD-Expedient Physical Fitness Test Scores

	Height	Body Mass	Vertical Jump	Horizontal Jump	2-Minute Push-ups	2-Minute Sit-ups
Body mass	0.44[a]					
Vertical jump	0.07	−0.17				
Horizontal jump	0.24	−0.22	0.71[b]			
2-minute push-ups	−0.09	−0.33	0.27	0.30		
2-minute sit-ups	0.36[a]	−0.28	0.12	0.33	0.35[a]	
3.2-km run	0.03	0.26	−0.21	−0.42[a]	−0.63[b]	−0.53[b]

[a]Value of $p < 0.05$.
[b]Value of $p < 0.01$.

TABLE III. Intercorrelations of the Test Scores of Simulated Battlefield Physical Performance

	400-m Run	30-m Rushes	Casualty Rescue
30-m rushes	0.87[a]		
Casualty rescue	0.45[b]	0.46[a]	
Obstacle course	0.64[a]	0.67[a]	0.19

[a]Value of $p < 0.01$.
[b]Value of $p < 0.05$.

mass was significantly associated with faster casualty rescue times and nonsignificantly associated with slower times on the other three military performance tests ($0.05 < p < 0.11$). Greater vertical and horizontal jumps, greater number of push-ups, and faster 3.2-km run time were all significantly associated with faster times on the 400-m run, 30-m rushes, and obstacle course. The ability to perform more sit-ups was significantly correlated with faster 30-m rush and obstacle course times, and almost significantly correlated with faster 400-m run time ($p = 0.053$).

We ran forward stepwise multiple linear regression procedures to determine the best linear equations to predict performance on the simulated military physical performance tests, using the field-expedient physical fitness scores and anthropometric measures as input. The equations are shown in Table V, with the order of the input variables from left to right indicating the order in which the regression procedure added them into the equation, all contributing significantly to predictive value. The equations, which contained two to four input variables, accounted for between 59% and 67% of the variance in each of the measures. When expressed as a percentage of the mean score, the standard errors of estimate (SEE) were 3.5% for 30-m rush time, 7.7% for 400-m run time, 10.9% for obstacle course time, and 14.7% for casualty rescue time.

DISCUSSION

The results on all four tests of simulated military physical performance were well-predicted by the linear regression equations using as input the anthropometric variables and scores on the field-expedient physical fitness tests, with r values ranging from 0.77 to 0.82. The vertical jump was the most useful variable, entering all four equations, two of them first. It appears that the jump reflects an ability to exert explosive lower body power, which is highly relevant to the kinds of high-intensity, short-duration activities that occur on a battlefield. None of the current Army physical fitness test events (push-ups, sit-ups, and 3.2-km run) reflect the ability to exert explosive lower body power. Second in value to the vertical jump as an input variable for the predictive equations was the 3.2-km run score, which entered three of the equations, one of them first. Duration of the simulated military physical performance tests averaged between 43 and 84 seconds, requiring a leg endurance component not reflected in vertical jump ability. That is provided by the 3.2-mile run time, even though that averaged close to 15 minutes. A 400-m unloaded run test, which could easily be administered as part of a military physical fitness test battery, might prove to be an even better military performance predictor as its duration would coincide more closely with those of the military performance tests.

The equation developed herein for prediction of obstacle course time was more effective than one developed by Bishop et al.[8] which included scores from tests requiring technical equipment and trained personnel. Interestingly, both the horizontal and vertical jumps came into our equation to predict obstacle course performance, with the horizontal jump entering first. The horizontal jump has a forward-driving component not present in the vertical jump, which likely accounts for the two jumps making independent predictive contributions. The forward-driving ability can be of value traversing various obstacles, such as the hurdles and stairs, and is also essential for acceleration between obstacles. The fact that the sit-up also enters the obstacle course equation likely reflects heavy involvement of the abdominal muscles in traversing the low crawl, horizontal pipe shimmy, and platform climb obstacles.

The predictive tests used in this study were all field expedient. In contrast, virtually all of the equations developed in other studies to predict military performance have included variables that can be measured only with specialized equipment and skilled personnel.[1–11] Such variables included VO_{2max}, various kinds of isometric strength, dynamic strength, fat-free body mass, and muscle cross-sectional area. The use of field-expedient tests makes the prediction equations practical for the military. Height and weight are easily measured and are already required semiannually of all U.S.

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TABLE IV. Correlations of the Anthropometric and Field-Expedient Physical Fitness Test Scores with Scores on the Tests of Simulated Battlefield Physical Performance

	400-m Run	30-m Rushes	Casualty Rescue	Obstacle Course
Height	0.05	−0.01	−0.20	−0.28
Body mass	0.29	0.30	−0.45[a]	0.35
Vertical jump	−0.54[a]	−0.72[a]	−0.31	−0.62[a]
Horizontal jump	−0.43[b]	−0.60[a]	−0.25	−0.69[a]
2-minute push-ups	−0.51[a]	−0.38[b]	0.16	−0.43[b]
2-minute sit-ups	−0.34	−0.37[b]	−0.01	−0.57[a]
3.2-km run	0.68[a]	0.53[a]	0.25	0.57[a]

[a]Value of $p < 0.01$.
[b]Value of $p < 0.05$.

TABLE V. Linear Regression Equations for Predicting Simulated Military Physical Performance Test Scores

30-m rush time (s):	−0.300 (vertical jump, cm) + 0.013 (3.2-km run time, s) + 62.5	$p < 0.001$, $r = 0.821$, SEE = 2.06
400-m run time (s):	0.058 (3.2-km run time, s) −0.582 (vertical jump, cm) + 61.3	$p < 0.001$, $r = 0.794$ SEE = 6.47
Obstacle course time (s):	−0.139 (horizontal jump, cm) −0.455 (situps, n) −0.595 (vertical jump, cm) + 152.7	$p < 0.001$, $r = 0.818$ SEE = 7.43
Casualty recovery (s):	−0.428 (body mass, kg) − 0.504 (vertical jump, cm) + 0.054 (3.2-km run time, s) + 0.416 (pushups, n) + 36.3	$p < 0.001$, $r = 0.769$ SEE = 6.35

soldiers, along with the push-up, sit-up, and 3.2-km run tests, which are only waived for medical reasons. The additional tests we used, the standing vertical and horizontal jumps, do not require more than a tape measure and wall.

The jump tests are very easy and quick to administer. The jump measurement devices used in this study are not necessary for such testing because vertical jumps can be measured by having examinees touch their chalked fingers against a wall to mark their jumps, and the long jumps can be assessed using a tape measure. Given their value for predicting simulated battlefield physical performance, the jump tests may be considered for inclusion in military physical fitness test batteries, especially for combat units. The fact that many activities on the battlefield involve very short, forceful exertions contributes to both the face validity and content validity of jump testing for combat soldiers. Of course, the addition of jump testing to military physical fitness test batteries would necessitate more emphasis in military training programs on improving jumping ability, which has been shown to be amenable to training, even for experienced athletes in jumping sports.[14] The Army's relatively new Standardized Physical Training,[15] which has already been mandated for basic training and advanced individual training, but not for line troops, does incorporate some jumping exercise. Because the promotion of enlisted personnel is affected by their physical fitness test scores, and unit leaders are responsible for improving the fitness scores of their troops, military units traditionally place the most emphasis in their physical training on exercises that raise physical fitness test scores. Thus, adding jump testing to military physical fitness tests would ultimately have the effect of improving the jumping ability of soldiers which, in turn, appears likely to improve their ability to fight and survive on the battlefield.

The highest correlation between any of the field-expedient physical fitness tests and anthropometric measures was between the two jump tests ($r = 0.71$), so that scores on each of the jumps explained about half the variance in scores of the other. Most of the other intercorrelations between the field-expedient physical fitness tests and the anthropometric measures were considerably lower, indicating that none of the tests could be used as a surrogate for any of the other ones. Overall, the lack of strong correlations between the test results suggests that they measure different attributes, conveying somewhat independent information.

The trend toward poorer performance on all of the field-expedient physical fitness tests with greater body mass can be attributed to two factors. First, smaller people tend to have a greater strength-to-body-mass ratio based on physiological considerations.[16] Heavier people have been shown to produce lower scores on military physical fitness tests, independent of body fatness.[17] Second, heavier people tend to be fatter and the fat weight that must be lifted and accelerated during each jump, running stride, or calisthenic repetition detracts from performance. For the same reasons, body mass also tended to hamper performance on three of the four simulated military physical performance tests: the 400-m run, 30-m rushes, and obstacle course. However, greater body mass was significantly associated with better performance on the casualty rescue. In this test, the volunteers experienced more resistance from dragging the 80-kg manikin than from moving their own bodies. For the other three simulated battlefield tests, the volunteers only carried the 18-kg fighting load, amounting to 18% to 30% of their body mass, but for the casualty rescue, volunteers had to drag the manikin, whose mass amounted to 80% to 125% of their body mass, and the frictional resistance was considerable. Since large people

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tend to have more muscle mass, bigger people were at an advantage in this event. Also, the increased momentum of a more massive body likely helped overcome frictional resistance of the manikin rubbing against the ground. Overall, heavier people appear to be at a disadvantage in manipulating the mass of their own body and a relatively light load, but at an advantage when external resistance is relatively high. On the battlefield, there are activities other than casualty rescue that also involve the manipulation of relatively heavy loads, e.g., setting up field artillery, hauling heavy weapons and ammunition, and moving obstacles. These are activities at which larger soldiers, who may not excel at physical fitness tests, could also be at an advantage.

Of all the field-expedient physical fitness tests, the 3.2-km run test produced the greatest number of significant correlations with the other field-expedient tests, suggesting that it would be the single most effective surrogate for the entire test battery. Yet, the correlations were not high enough to indicate that it should be the only physical fitness test. Of all the field-expedient physical fitness and anthropometric tests, the 3.2-km run test and the jumps were the best predictors of scores on the tests of simulated battlefield physical performance in that better performance on the jumps and 3.2-km run tests was significantly associated with better performance on the 400-m run, 30-m rushes, and obstacle course, with trends toward better casualty rescue performance as well.

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