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THE DIMENSIONS OF PHYSICAL FITNESS— A FACTOR ANALYSIS OF STRENGTH TESTS

by

EDWIN A. FLEISHMAN, ELMAR J. KREMER, and GUY W. SHOUP

Technical Report 2

Prepared under Contract Nonr 609(32) for the Office of Naval Research

DEPARTMENT OF INDUSTRIAL ADMINISTRATION
AND DEPARTMENT OF PSYCHOLOGY
YALE UNIVERSITY
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FOREWORD

This report describes the second in a series of studies under the general project title "The Development of Criteria of Physical Proficiency." This project is supported by funds provided under Contract Nonr 609(32) between Yale University and the Office of Naval Research.

The background and objectives of this program have been described in Technical Report 1 in this series. The overall objective is the identification of the components of physical proficiency and the development of appropriate tests to measure these components. Technical Report 1, by Nicks and Fleishman, reviewed the literature on previous factor analytic research on the dimensions of physical fitness. The present report, Technical Report 2, describes the first large scale follow-up study conducted at the Great Lakes Naval Training Center, Illinois. This study is an attempt to conceptualize the area of "strength" measurement and to provide recommendations for tests in this area. Technical Report 3, by Fleishman, Thomas, and Munroe, describes a parallel study (carried out at the San Diego Naval Training Center), in which we defined the factors measured by tests of speed, flexibility, balance, and coordination.

The present study is the product of the efforts of a great many people and it would be difficult to acknowledge all of them. The late Dr. Delmer C. Nicks contributed much to the initial planning of the study. Mr. Guy Shoup and Mr. Elmar Kremer were

research assistants during the test development and data collection phases of the study. They, together with Mr. William Yohn, supervised the testing at the Great Lakes Naval Training Center, which was carried out during the summer of 1959.

At the Great Lakes Naval Training Center we are indebted to Captain Carl E. Bull, Commanding Officer, and to Commander Henry L. Vaughan, Executive Officer, Recruit Training Command, for their assistance and support. Especially valuable assistance was received from Lieutenant Commander Gordon C. Hopwood, Training Officer, Lieutenant Ronald B. Clontz, Ensign W. T. Healy III, and many other officers in the various training departments. The twelve petty officers, temporarily assigned to our testing team, served admirably as test administrators.

We also appreciate the assistance of the staff of the Payne Whitney Gymnasium at Yale during the test development phase of this research. These unmatched facilities were made available to us, and we are especially grateful to Mr. Robert Kiphuth, now Professor of Physical Education Emeritus, and to Mr. Oscar W. Kiphuth, Assistant Gymnasium Director.

Some of the pretesting was carried out in local high schools, and we would like to give a special acknowledgement to the physical education staff at West Haven High.

The authors also acknowledge the expert statistical services provided by Dr. Benjamin Fruchter, University of Texas. In addition to Mr. Kremer and Mr. Shoup, Mr. Gaylord Ellison and

Mr. Robert Fleishman provided tabulational and computational assistance during this period. We also appreciate the valuable contributions of Mrs. Carolyn Talalay, project secretary, and Miss Julie Merkt, departmental secretary.

Appreciation for their continued support in connection with the contract is extended to Dr. Denzel D. Smith, former Head, Psychological Sciences Division, and to Dr. Glen Bryan, Head, and Mr. John Nagay, Assistant Head, Personnel and Training Research Branch, all in the Office of Naval Research. We also acknowledge the support of the Chief of Naval Personnel in facilitating the testing arrangements at Great Lakes.

Edwin A. Fleishman, Ph.D.
Project Director

The Dimensions of Physical Fitness - A Factor Analysis of Strength Tests.

This is another in a series of studies (Hempel & Fleishman, 1955; Nicks & Fleishman, 1960; Fleishman, Thomas, and Munroe, 1961) concerned with the isolation and definition of factors in physical proficiency. This work is an outgrowth of earlier research on the structure of human perceptual-motor abilities (Fleishman, 1953, 1956a, 1956b, 1957, 1958a, 1958b; Fleishman & Hempel, 1954a, 1954b; Fleishman & Hempel, 1956; Fleishman & Ornstein, 1960; Parker & Fleishman, 1960). One objective of our work on physical fitness is the eventual development of a comprehensive battery of tests to measure the physical fitness factors identified.

A previous report (Nicks & Fleishman, 1960) reviewed and integrated previous factor analysis work in the area of physical fitness measurement. The review described fourteen physical proficiency factors previously identified, discussed other possible factors which might be discovered, and raised a number of questions regarding the structure of skill in this area. We also suggested several large scale follow-up studies needed to clarify factor definitions and to answer the questions raised. The present report describes the first of our large scale follow-up studies. Specifically, the area of strength measurement was investigated.

Our earlier review showed that three broad strength factors had emerged from previous research, although the names assigned these factors by different investigators varied. We called these three factors Dynamic Strength, Explosive Strength, and Static Strength. In addition, there were suggestions of separate factors within these areas which corresponded with the involvement of arm, leg or trunk muscles. The possibility that strength factors might correspond to broader muscle groupings (e.g. flexors vs. extensors) was also suggested. These previous studies also left unclear the role of "endurance" in various strength tests as well the relation of running tests to possible endurance and strength factors.

The present study was designed to investigate these questions. More specifically the study attempts to 1) clarify the generality and limits of strength factors in a wider range of tasks, 2) sharpen our definitions of these factors, and 3) discover which tests provide the best assessment of the factors identified.

PROCEDURE

The approach is a correlational approach. Tests are first selected or developed with certain hypothesized ability factors in mind. (For example, "push-ups" might be selected to measure a hypothesized factor of "arm strength"). A large number of such tests are administered to a large number of subjects. From the correlations among these test performances, inferences are made about the common abilities needed to perform them. Thus, if individuals who perform well on push-ups, also perform well on "chins" (that is, there is a high correlation), then there must be some common requirement between these two tasks. We might even infer that this common requirement is "arm strength," but what if there is only a low correlation with other tasks (e.g., lifting weights) requiring arm strength? In this case "arm strength" would be too broad a factor name and we would have to look for other, clarifying, relationships. With a larger number of tests it becomes increasingly difficult to group tests according to common factors, and some tests may fall on more than one factor. The technique of factor analysis, used in our studies, is a mathematical solution to this problem. This technique starts with the correlations among the tests and groups the tests in terms of a more limited number of more "fundamental" factors.

Hypothesized Factors and Test Development

The literature review previously reported (Nicks and Fleishman, 1960) served as a source of hypotheses for test development. This review concluded that the diverse strength factors, identified in previous research, could be reduced to three general strength factors called Dynamic Strength, Static Strength, and Explosive Strength. In the present study attempts were made to include widely used tests throughout to tap these factors along with a variety of new tests developed to throw light on the generality and limits of these factors.

Furthermore, this previous review revealed inconclusive evidence on the existence of additional factors in this area. Every effort was made to allow for the possible appearance of such factors in our present study. Thus, within each of the three broad factor categories, systematic test variations were introduced. For example, Dynamic Strength might emerge as a separate factor, but are there separate Dynamic Strength factors confined just to arms, legs, or trunk muscles? To evaluate this, we made sure to include at least three arm, three leg, and three trunk "dynamic strength" tests. Since one previous study had suggested separate (but highly correlated) factors representing arm extensor and arm flexor muscles, we allowed for the possible appearance of these factors by including arm extensor and arm flexor tests. Similarly, among the Explosive and Static Strength tests we provided tests emphasizing different muscle groups.

The role of "endurance" in strength tests was evaluated by comparing tests requiring subjects to hold static positions of strain for prolonged periods (see, for example, "Bent Arm Hang," "Hold Half Push-up"), with other tests which required continued exercise of these arm muscles for as long as possible (see "Chins," "Push-ups"). Still other tests attempted to rule out "endurance" altogether by invoking short time limits (e.g., "Do as many chins as possible in 20 sec."). Would one or more separate endurance factors emerge?

The inclusion of sprint and run tests was aimed at clarifying the role of endurance and strength factors in such performances. Do short runs, for example, depend more on Explosive Strength, than do longer runs?

There were other questions investigated. Are there common factors which cut across muscle groups? Are there common factors confined to muscle groups? For example, do all arm tests fall on a general "arm strength" factor regardless of whether Dynamic, Static, or Explosive Strength is required?

With these kinds of questions in mind the reader is referred to Exhibit A. Exhibit A summarizes the framework used to develop the thirty tests in the experimental test battery. It shows the hypothesized factors and the tests included to "measure" each factor. It can be seen that a minimum of three tests were included to "overdetermine" each hypothesized factor. The design allowed for the appearance of a few broad general factors, for a large number of narrow factors, or for combinations of broad and narrow factors. It should be stressed that Exhibit A does not exhaust the possibilities allowed for. Thus, it is possible that a single "endurance" factor or a separate "speed" could emerge. The important point is that Exhibit A generated our test selection and development program and that the resulting analysis could have resulted in a wide variety of different solutions.

Pre-testing and Pilot Studies

Many more tests were tried out before these particular thirty tests finally were selected. For example, we attempted to develop "punching bag" and "kick force" tests, utilizing force measuring attachments, to tap "explosive strength-arms" and "explosive strength-legs," respectively. These were discarded because the "accuracy" component could not be reduced

Exhibit A

Possible Strength Factors Hypothesized in the Experimental Tests

	Possible Primary Factors: Dynamic Strength Arms		Dynamic Strength		Endurance			Explosive Strength		Possible General Factors				
	Flex.	Ext.	Legs	Trunk	Dynamic	Static	Runs	Arms	Legs	Dynamic Strength	Static Strength	Explosive Strength	Arm Strength	Leg Strength
1. Leg Lifts			x							x				
2. Push-ups (in 15 sec.)		x								x			x	
3. Reverse Sit-ups				x						x				
4. Deep Kneebends			x							x				x
5. Sit-ups				x						x				
6. Squat Thrusts			x							x			x	
7. Pull Weights	x									x	x		x	
8. Hand Grip											x			
9. Push Weights-Arms		x								x	x		x	
10. Arm Pull-Dyna.											x		x	
11. Push Weights-Feet			x							x	x			x
12. Trunk Pull-Dyna.											x			
13. Rope Climb	x									x			x	
14. Dips (in 10 sec.)		x								x			x	
15. Vertical Jump									x			x		x
16. Dips (to limit)		x			x					x			x	
17. Standing Broad Jump									x			x		x
18. Leg Raiser				x		x				x				
19. 10 Yard Dash							x		x			x		x
20. Bent Arm Hang	x					x				x			x	
21. 50 Yard Dash							x		x			x		x
22. Chins (to limit)	x				x					x			x	
23. Shuttle Run							x		x			x		x
24. Chins (in 20 sec.)	x									x			x	
25. Medic. Ball Put (stand.)								x				x	x	
26. Hold Half Sit-up				x		x							x	
27. Medic. Ball Put (sit.)								x				x	x	
28. Hold Half Push-up		x				x				x			x	
29. Softball Throw								x				x	x	
30. Push-ups (to limit)		x			x					x			x	

sufficiently. Other tests (e.g., those using wall weights and pulleys) were found impractical or possibly dangerous to the subject. Many tests were discarded because of low reliability, difficulties in administration, standardization or scoring, lack of discrimination among individuals, equipment construction problems, etc.

All of the tests retained received considerable pre-testing and standardization. Pre-tests were carried out with high school senior students in the New Haven area and with Yale freshmen in the Payne-Whitney Gymnasium. Considerable refinements in test administration procedures and revisions in time limits were worked out at this stage. In most cases original time-limits had to be shortened, since too many subjects were reaching their limits even within our original short time periods. The attempt was made to shorten time limit tests to the point where subjects still had strength to continue, but where the test was long enough to provide a sufficiently reliable measure. We were surprised (and gratified) that some tests could be shortened to trials of 10 seconds, yet still provide sufficient reliability. (The reliabilities for the final administrative conditions of each test used in the main study are presented in Table 1.)

We should also point out that many of the test procedures for familiar tests were modified over standard practice in order to "purify" the measures. For example, our Vertical Jump test did not allow the reaching-up and stretching movement typically used. In our procedure, the subject kept his hands at his sides during the jump. This was to emphasize "explosive strength" in the legs and to minimize trunk and arm "flexibility." In "Softball Throw" we used a larger, 15 inch ball and required the subject to keep his feet in place; this was to reduce "coordination" and skill factors and to emphasize "explosive strength" and arm-shoulder involvement. "Rope Climb" was made from a standing position and with arms only, to emphasize the use of the arms and to reduce possible "explosive strength" contributions. Modifications of this type had the primary purpose of emphasizing, as far as was possible, the main factor hypothesized to contribute to performance on each test.

Test Descriptions

A brief description of each test follows. As used in these descriptions, the term "Time Limit" test indicates that the subject had a set time to complete the test; "Timed" indicates that a subject's score was the time it took him to complete the test; "To Limit" indicates no timing was involved but the subject continued as long as he was able to. In each type of test, the examiners made every effort to keep the subjects performing at their maximum level.

Test 1 - Leg Lifts - Time Limit (Figure 1). The subject lay flat on his back, hands behind his neck, with his elbows held to the floor by a partner. He then raised his legs until they were vertical, and then returned them to the floor. He was told to do as many of these lifts as he could in 20 seconds, after the signal "go." He was required to keep the small of his back and the base of his spine on the floor. Efforts to boost the body or to "rock" were not allowed. A stiff one-two motion was used with the legs straight at all times. A demonstration was given and the subject tried the movement twice before the actual test. Score was the number of times the legs are elevated to a vertical position in the 20 seconds.

Test 2 - Push-ups - Time Limit (Figure 2). The subject was told to do as many push-ups as possible in 15 seconds. In a prone position, his hands were beside the chest, fingers pointed forward. His hands were placed far enough apart so that the forearms made a right angle with the floor. Feet were together, body straight, and only chin and chest allowed to touch the floor. The body was raised until the arms were stiff, and the back was not to be arched. Score was the number of push-ups in 15 seconds.

Test 3 - Reverse Sit-ups - Time Limit (Figure 3). The subject lay on the floor with hands behind his neck; his partner held his legs to the floor. He then raised the upper half of his body as high as possible. This height was noted, and the subject returned to his original position. On the signal "go," the subject has to repeat as many of these "reverse sit-ups" as possible in 20 seconds, raising his torso as far as possible (the first trial position) each time. The "one-two," sharp movement required (as opposed to a rolling movement) was first demonstrated. Score was the number of times the subject raised himself in 20 seconds.

Test 4 - Deep Knee Bends - Time Limit. The subject started in an erect position. At the "start" signal he lowered himself to a full squat (trying to touch his heels), and then returned to the erect position. To keep his balance he was advised to fix his eyes on a given point and he was allowed to extend his arms. (Under this speeded condition too many lose their balance in the "hands on hip" position.) The subject tried to do as many such deep knee bends as possible in 30 seconds. Score was the number of times he returned to the starting position in 30 seconds.

Figure 1. Leg Lifts.

Figure 2. Push ups. (see tests 2, 26, & 30)

Figure 3. Reverse Sit-ups.

Figure 4. Sit ups. (see tests 5 & 28)

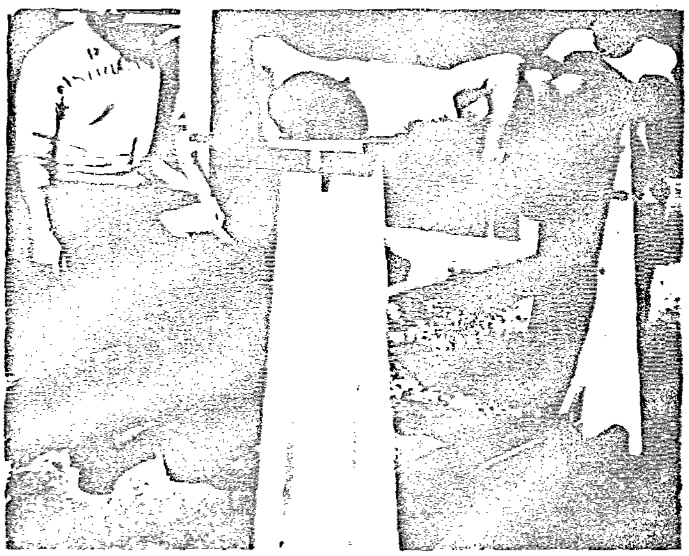

Figure 5. Pull Weights - Arms.

Test 5 - Sit-ups - Time Limit (Figure 4). The subject was on his back, hands clasped behind neck, with a partner holding his legs down at the knees. He pulled himself up to a vertical position as many times as possible in 30 seconds. Both shoulder blades were required to touch the deck before each sit-up and he was cautioned that his trunk was not to go further forward than a 90 degree angle with the floor; he was not allowed to touch his knees. To emphasize the trunk, jerky movements were discouraged and the hands were kept behind the neck (not behind head). The exercise was done rapidly and continuously. A demonstration was given and the subject tried it two or three times to get the feel of it. Score was the number of times the vertical position was attained in 30 seconds.

Test 6 - Squat Thrust - Time Limit. Facing the floor and with arms outstretched, the subject placed his hands on the floor just forward of his shoulders. He supported the body, legs outstretched, in this way. A the signal "go," he was required to jump his legs up under his body to a position where his heels touched his buttocks; he then returned his legs to the fully extended position. He was required to repeat this cycle as many times as possible. Score was the number of times the subject returned to the starting position in 30 seconds.

Test 7 - Pull Weights-Arms - Time Limit (Figure 5). The subject lay face down on a bench four feet high, 6 feet long, and 1 foot wide. He was handed a barbell under the bench, which he gripped with palms backward. He then pulled the bar up to the bench under him. His hands were spaced so that his forearms were perpendicular to the floor, in this position. After two "familiarization" cycles, the arms were returned to the extended downward starting position. At the signals "ready" and "start," he was required to pull the bar up, until it touched the underside of the bench, and then to lower it to a fully extended position as many times as possible in 20 seconds. The subject was cautioned to use a smooth motion, not to bounce the bar off the bench, not to jerk his shoulders or any other part of his body off the bench. To place further emphasis on the arms, his partner held the subject's lower legs down. A cushioning towel was placed under his head and a second observor held the subject's head lightly by placing one hand on each side of his head. The weight of the bar was 17 lbs. plus added weights of 20 lbs. This 37 lbs. was found "liftable" enough for the emphasis on speed. Score was the number of times the subject returned the barbell to the start (extended) position in 20 seconds.

Test 8 - Hand Grip. A Narragansett Co. grip dynamometer, calibrated from 0-200 lbs. was used. The subject used the hand he thought strongest. The dynamometer was placed in his palm, dial up, fingers curled over so that part of the fingers between the second and third knuckles were touching the grip. The subject held his arm down at his side, away from his body. He was not allowed to rest his forearm against his body. At the command "squeeze," he was told to squeeze the dynamometer once, sharply, as hard as possible. He was given three "squeezes," with at least 30 seconds between trials. Score was the best of his three squeezes.

Test 9 - Push Weights-Arms - Time Limit (Figure 6). The subject lay face up on the bench (see Test 7), with his feet flat on the floor. He was handed the 37 point barbell (see Test 7), with his palms facing his feet. With the barbell close to his chest, the hands were spaced just wide enough so his forearms were perpendicular to the floor in this position. He pressed the barbell twice to familiarize himself with the proper movement. In the "start" position the bar was held with the arms fully extended upward. He was required to bring the bar down to within an inch of his chest, then press it back up to the start position. Speed was emphasized. He was cautioned not to bounce the bar off the chest and to keep the back and head on the bench at all times. As in Test 7, one partner held his knees down on the bench, while another held his head lightly. Score was the number of times the barbell was returned to the start position in 20 seconds.

Test 10 - Arm Pull - Dynamometer (Figure 7). The position in which this test was given is shown in Figure 7. Special springs (ordered to allow measurements up to 450 lbs.) were inserted in the grip strength dynamometer (see Test 8) and the whole assembly inserted into the adapter handles. One handle was attached by a strap to a pole, the subject gripped the other handle (with his "strongest arm") while bracing himself against the pole with his free arm. When the signal "pull" was given, the subject pulled on the dynamometer handle as hard as he could. The forearm and legs had to be kept straight. The straps were adjusted for each subject's arm length. The subject made three such "pulls" with a minimum of 30 seconds between trials. Score was the best of his three pulls.

Test 11 - Push Weights-Feet - Time Limit (Figure 8). The subject was fitted with "iron boots" over his shoes. These "boots" allow the insertion of a single bar, through the two boots, with additional weights. The shoes each weighed five pounds and the added barbell weighed 17 pounds. The subject then lay on his back and raised the weights up until, with legs fully extended, the weight was balanced over his head. This was the "start" position. He was given assistance in this balancing by a partner. To further assist this balancing and to emphasize the leg involvement a four inch mat was rolled 22 inches high to

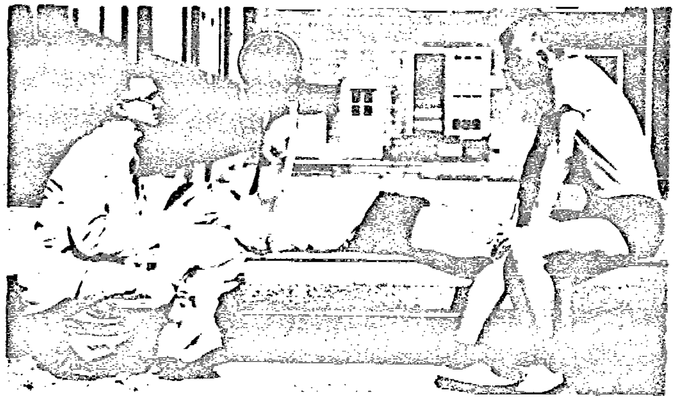

Figure 6. Push Weights - Arms.

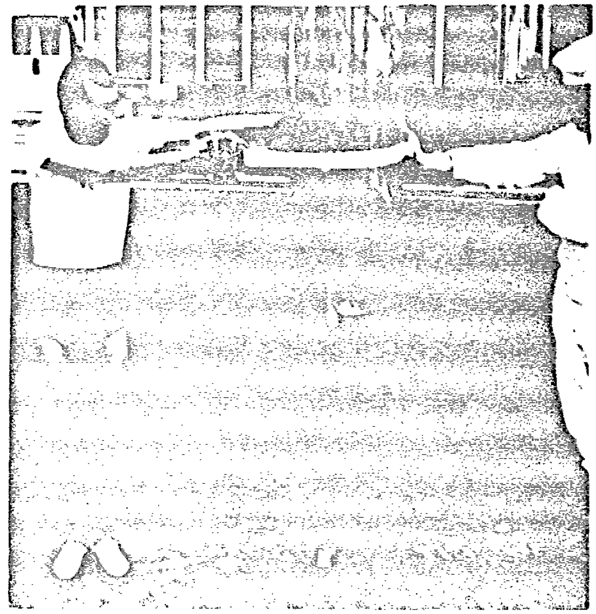

Figure 7. Arm Pull - Dynamometer.

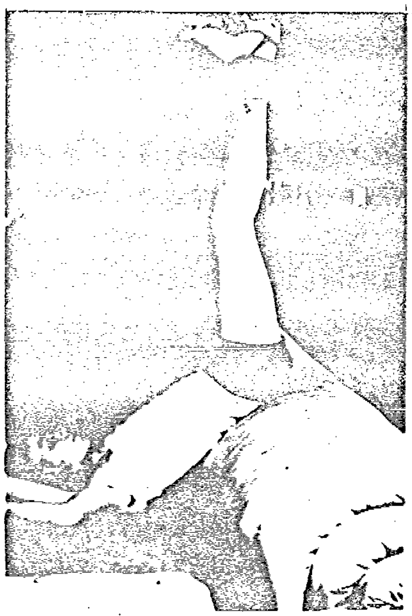

Figure 8. Push Weights - Feet.

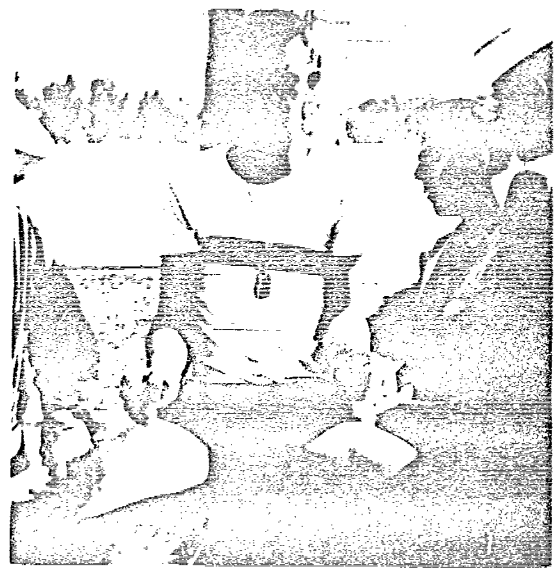

Figure 9. Trunk Pull - Dynamometer.

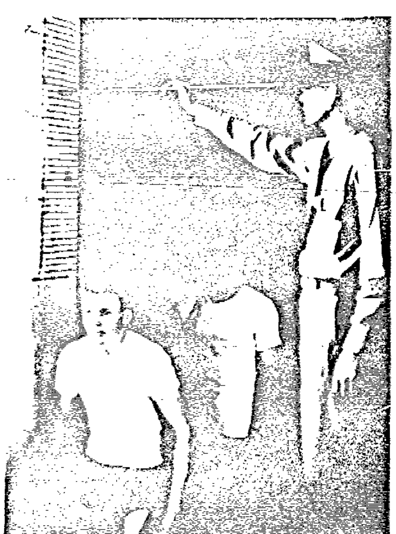

Figure 10. Vertical Jump.

provide support under the small of his back. The subject practiced the sequence of a) lowering the weight as far as possible by bringing his knees down toward his chest, and then b) pushing the weight back up by straightening his legs. After a "ready," then "start" signal the subject repeated this cycle as fast as possible. Score was the number of times the subject returned the barbell to the start position in 20 seconds.

Test 12 - Trunk Pull - Dynamometer (Figure 9). Figure 9 shows how the dynamometer assembly used for Test 10, was adapted for this test. A strap was fitted around the subject's chest, as high as possible. This strap was attached to one handle of the dynamometer while another strap attached the other handle to a pole. The subject sat straight up and on the signal "pull" he leaned forward as hard as he could. A partner sat on his knees to emphasize trunk involvement. Score was the best of three such pulls.

Test 13 - Rope Climb - Time Limit. The subject grasped the rope as high as he could in a standing position. This reaching height was recorded. On the signal "start," he pulled himself up the rope as fast and as high as possible. He was not allowed to jump up on the rope, nor could he use his knees or legs to grasp the rope in climbing. The emphasis was on the arms. At the signal "stop" (after 6 seconds), his highest reach on the rope was recorded as his climbing height. The rope was 20 feet high marked with adhesive tape every foot and with colored tape every five feet. One examiner controlled the stopwatch, while the other watched the rope at all times. Score was the subject's climbing height in six seconds minus his initial reaching height.

Test 14 - Dips - Time Limit. The subject supported himself between parallel bars (Medart Co., 5' 2" high, 25" separation at center) with his arms stiff. At the signal "start," he lowered himself until there was a 90° angle between his forearm and upper arm, with his upper arm parallel to the floor. He was cautioned that lowering past this position would make it much harder for him to raise himself again, and he was required to raise himself all the way up to the start position to complete a cycle. After a demonstration, the subject was required to go as fast as he could for 10 seconds. (Actually, this was found to be somewhat too long, as these subjects found this exercise a very tiring one.) Score was the number of times the subject returned to the start position in 10 seconds.

Test 15 - Vertical Jump (Figure 10). The subject jumped straight up as high as he could, next to a wall, without raising his arms. The observer stood to his side on an 18 inch stool and held a light 24" rubber tipped pointer stick (about 1/2 inch diameter) over the subject's head. The first jump gave the observor a general indication of the subject's jumping height. On subsequent jumps the observor placed the pointer against the scale mounted on the wall and watched to see if the subject knocked the stick up. After three or four jumps, the height of the best jump was recorded. Score was this height minus the subject's height.

Test 16 - Dips - To Limit. This was performed in the same manner as Test 14, except the subject was instructed to continue to do as many dips as he could. He was told not to stop in the "up" or "down" position for more than three seconds. If he started to sway excessively, the observor placed his palm against his legs to stop the swaying. Score was the total number of times the subject returned to the starting position without stopping for 3 seconds at any point.

Test 17 - Standing Broad Jump. The subject put his toes up to a start line and then jumped as far forward as possible. The jump was performed on a mat marked off in two inch units. He was allowed to do anything with his arms. He was told that if he fell backwards the jump would not count. Score was the best jump out of three, as measured from the start line to the rear of the foot closest to the start line at impact.

Test 18 - Leg Raiser - Timed (Figure 11). The subject lay flat on his back, hands clasped behind neck. At the signal "go" he raised his heels until they were 14 to 16 inches off the floor and held them there, legs straight, as long as he could. To emphasize trunk muscles, the back of his head, small of his back, and elbows had to touch the floor at all times. (The partner held his elbows down.) An observor kept a pencil under the subject's legs to make sure he did not drop his legs below (approximately) 14 inches. Defects in position were corrected immediately by the observor. Examiners made special efforts to keep the subjects from "giving-up" by exhorting them to continue at every sign of "let-down." Score was the number of seconds from "go" that the subject kept his legs in the air.

Test 19 - 10 Yard Dash - Timed. Subjects started with one knee on the ground and fingers on starting line. They were told "First, 'take your mark' at which you will be ready for the starting commands. Second; 'get set.' With this raise your body off your haunches and get yourself balanced properly, as far forward as possible, for the start. Do not lean too far forward - you may cause a false start. At the command "go," run. Straighten up before you reach the tape, but not immediately if you feel it will slow you down. Most important is to get off your marks as fast as possible." Observors were careful to watch the subject's balance in the "get set" position. The subjects ran

Figure 11. Leg Raiser.

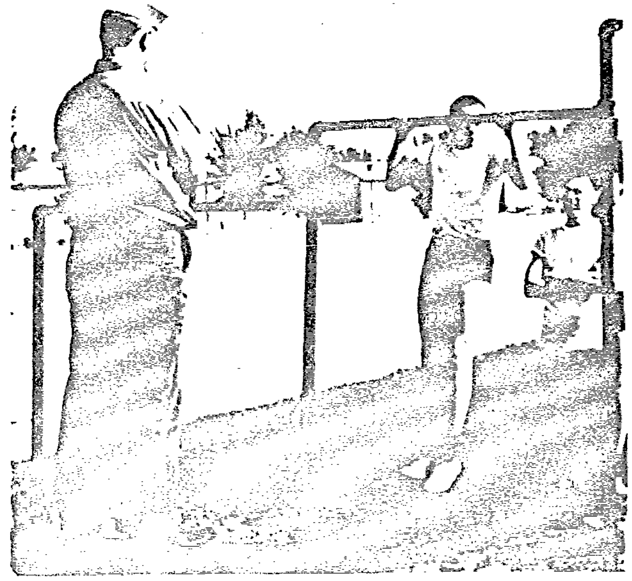

Figure 12. Bent Arm Hang (see also tests 22 & 24)

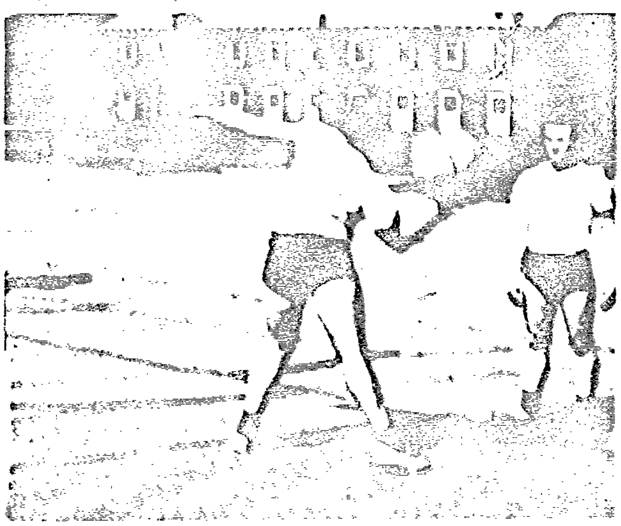

Figure 13. Medicine Ball Put - Standing.

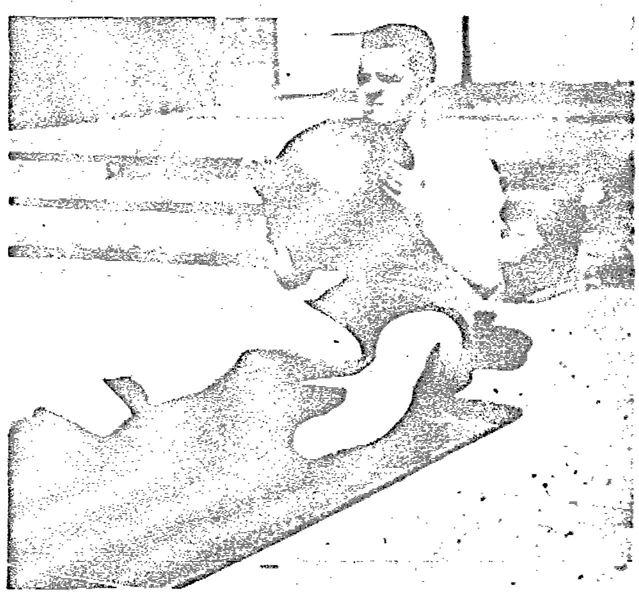

Figure 14. Medicine Ball Put - Sitting.

and were timed individually in two separate runs. Score was the fastest time (to tenth of second) for the two sprints.

Test 20 - Bent Arm Hang - Timed (Figure 12). After a demonstration, the subject pulled himself up to the chinning bar until his eyebrows were level with the middle of the bar. The subject was required to keep this position as long as he was able to. The observor stood on a bench with his eyes level with the bar. The subject was not allowed to touch any part of his head to the bar nor to kick or struggle or move his body. The observor allowed no more than one inch deviation in "eyebrow" position. Palms faced away from the body. As in Test 18, special efforts were made to keep the subjects in position, especially as they began to tire. The bar used was 1 3/4" in diameter and was 6 feet 8 inches above the ground. Score was the number of seconds in the proper position from the signal "go."

Test 21 - 50 Yard Dash - Timed. Same as Test 19, except for the distance. Two observors recorded the time and these were averaged. Score was time (to nearest tenth of a second) for one dash.

Test 22 - Chins - To Limit. This was the familiar "pull-ups" test with some modification. At the start, the subject hung from the bar with palms facing toward the body. At the "start" signal he pulled himself straight up until his chin was just over the bar, and then he let himself down until his arms were fully extended to complete the cycle. The subject was told to continue until unable to do any more. He was cautioned against kicking and twisting, or stopping in any one position for more than two seconds. Observors stopped excessive swaying. The examiner counted aloud and if the subject's arms were not fully extended, or if the chin did not reach the bar, he counted "one-half" instead of "one." The examiner demonstrated one "chin." The bar used was 1 3/4" in diameter and was 7 feet 10 inches off the ground. Score was the number of chins completed.

Test 23 - Shuttle Run - Timed. Two parallel lines, 20 yards apart, were marked off on the macadam surface. The subject stood with one foot on the starting line, and at the command "go!" ran the 20 yards to the second line, touched the ground on the other side with either foot, and returned to the start line. He repeated this, until he had covered the 20 yards five times. On the last lap, upright standards and a finish tape were put up for the runner to break. It was found that turns between "laps" averaged a radius of about 6 feet. If the subject made these turns in some grossly inefficient way, he was encouraged to turn around more efficiently. Observors were stationed at each line. Two observors recorded the time. Score was the average of these two times for the one complete run.

Test 24 - Chins - Time Limit. Same as Test 22 except the subject was told to chin as fast and as many times as possible in 20 seconds. Score was number of complete chins in 20 seconds.

Test 25 - Medicine Ball Put - Standing (Figure 13). The medicine ball used weighed 9 pounds. The subject "held" the ball in his preferred hand and balanced it with his other hand. He placed his forward foot on the back of a "base line" and positioned his other foot in a comfortable position. Once in place he was not permitted to move his feet although he could twist his body. This was to emphasize the arm-shoulder involvement and to minimize the leg contributions. The subject was to throw the ball as far as possible with the one hand. If his "form" was wrong, the throw did not count, but he was allowed three correct throws. Score was the distance, in feet, of the best throw.

Test 26 - Hold Half Sit-up - Timed (Figure 4). The subject lay on the floor. His partner straddled his legs with his hands on the subject's knees. The subject's hands were behind his neck, elbows spread, but his hands did not touch the back of his neck. (This was to avoid additional support furnished by such "bracing.") On the signal "start," the subject sat up until the upper half of his body was half-way to a sitting-up position (roughly a 40 degree angle with the floor). He was to hold this position as long as he possibly could. The examiner first demonstrated, then had the subject try it briefly while the partners noted his position. Emphasis was placed on keeping the body rigid, with chest out, stomach in. Discrepancies were corrected immediately. As in other endurance tests, every effort was made to keep the subjects trying. One observor counted the number of seconds, while the partner noted the time when the subject dropped. Score was the number of seconds subject remained in position.

Test 27 - Medicine Ball Put - Sitting (Figure 14). The subject sat so his outstretched arms were even with a base line. The 9 lb. medicine ball was marked on each side with adhesive tape. The subject grasped the ball with his palms on each side of the ball at the tape. His hands were not allowed behind the ball, and he was not to cock his wrists. The ball was brought back to the chest and pushed out from the body as far as possible. To further emphasize the arms, he was not allowed to move from his sitting position while putting the ball. He was given three trials. Score was the distance the ball was propelled in the best trial.

Test 28 - Hold Half Push-up - Timed (Figure 2). Subjects lay prone in the standard push-up position (see Test 2), legs and feet together. Hands on the floor were far enough away from body so that 90 degree angles could be formed by the forearm with the floor and with the upper arm when the subject pushed himself up. Subjects received a demonstration, and a brief tryout of the correct position. At the signal "start," the subject raised his body to this half push-up position. Back, legs, neck, and head were to remain straight and in line. Hands were spread. Immediate corrections were made at the start if the head sagged, back arched, legs bowed, etc. The 90 degree angle at the elbow had to be maintained. The subject held this position as long as he possibly could. Score was the number of seconds he could maintain this position.

Test 29 - Softball Throw. The subject threw a 15" softball as far as possible without moving his feet. He was allowed to throw with either hand. Bricks with painted numbers marked off the field every five yards. Two observors spotted the point of impact, while a third stood at the throwing area. Score was the best distance in three throws.

Test 30 - Push-ups - To Limit (Figure 2). Same as Test 2, except the subject was instructed to continue as long as possible. He was cautioned against remaining in any one position more than two seconds. Score was the total number of push-ups completed.

Administration of the Main Study at Great Lakes

A testing team was established at the U. S. Naval Training Center, Great Lakes, Illinois. This team included three research assistants from the project at Yale, each of whom had participated in the development and pre-testing of the test procedures. They in turn, were assisted by twelve senior Petty Officers assigned to us as test administrators. All of these petty officers were swimming instructors and were graduates of the Navy Class C Instructor School. Each Petty Officer was given special training in the administration of those tests for which he would be responsible. They worked under the supervision of the project personnel. To further standardize and control the testing conditions, the partner system was used in which other recruits assisted in the testing (see test descriptions above). The Petty Officers were very interested in the project and highly motivated to get the maximum performance from these recruits.

The administration order of the tests was determined from joint considerations of 1) fatigue effects (e.g. tests involving the same muscles were not given successively, runs were given in separate sessions, endurance tests were widely separated), 2) the number of test administrators we had, 3) traffic flow from group tests to individually administered tests, and from indoor to outdoor facilities, and 4) the number and sequence of hours we could arrange in the subjects' regular basic training schedule. The schedule worked out is summarized in Figure 15, which shows the subject's score card. It can be seen that the tests were grouped into three sessions, where each session was approximately 2 1/2 hours. Three companies of Naval trainee recruits (approximately 70 subjects each) were tested separately. This means that there were 9 testing sessions (plus an extra final session for those subjects who missed an earlier session) and that it took about 7 1/2 hours to test a group of 70 on all tests. Sessions were spaced through six days so that no group went through more than one session per day. Within each of the sessions indicated in Figure 15, subjects proceeded, in order, from one testing station to the next. In all, 201 subjects went through the complete battery in the main study.

The indoor tests were administered inside a well ventilated gymnasium approximately 100 feet by 50 feet, and 30 feet high. The outdoor tests were administered on an adjacent asphalt area (100 yards x 100 yards) as well as on nearby grass surfaces. Except for the first day, when the outside temperature dropped to 57°, the maximum temperatures were in the 70-80° range, with no wind of any consequence.

The subjects were in their sixth week of basic training. They wore sneakers, T shirts, and shorts for the tests. They received an orientation from their commanding officers and from project personnel stressing the importance of the testing. There was every indication that the subjects were highly motivated to do their best; and there was a competitive spirit. To further increase motivation they were told that the top performances in each event would be posted within the following week. (They were posted!)

Background and athletic experience variables.

In the initial orientation, the subjects filled out identifying information on their own score cards. Figure 16 shows the information called for on the back of these cards. This information, together with the subject's General Classification Battery test scores (looked up separately), provided us with 11 supplementary variables, to add to our 30 test variables, in our correlational study. In subsequent tables, these variables are as follows:

31. Height
32. Weight
33. Age
34. General Classification Test - a measure of "general intelligence," administered to all incoming recruits.

PHYSICAL FITNESS PROJECT

	SESSION I		SESSION II		SESSION III	
GROUP TESTS	Leg Lifts (20 sec.)	Pushups (15 sec.)	Reverse Sit-ups (20 sec.)	Deep Knee Bends (30 sec.)	Situps (30 sec.)	Squat Thrusts (30 sec.)
INDIVIDUAL TESTS — INDOOR	Pull Weights -Arms (20 sec.)	Hand Grip 1____ 2____ 3____	Push Weights -Arms (20 sec.)	Arm Pull-Dynamom. 1____ 2____ 3____	Push Weights -Feet (20 sec.)	Trunk Pull-Dynamom. 1____ 2____ 3____
INDIVIDUAL TESTS — INDOOR	Rope Climb (6 sec.) Subject reach____ Climb height____	Dips (10 sec.)	Vertical Jump Subject height____ Jump height____	Dips (limit)	Standing Broad Jump 1____ 2____ 3____	Leg Raiser
INDIVIDUAL TESTS — OUTDOOR	10 Yard Dash 1____ 2____	Bent Arm Hang	50 Yard Dash 1____ 2____	Chins (limit)	Shuttle Run Time 1____ Time 2____	Chins (20 sec.)
INDIVIDUAL TESTS — OUTDOOR	Medicine Ball -Standing 1____ 2____ 3____	Hold Half Situp	Medicine Ball -Sitting 1____ 2____ 3____	Hold Half Pushup	Softball Throw 1____ 2____ 3____	Pushups (limit)

NAME ______________________ SERVICE # ______________

Figure 15. Subject Score Card (Side One)

PHYSICAL FITNESS STUDY I

GROUP

Name ______________________

Service # ______________________

Company ______________________

Height __________ Weight __________ Age __________

Hometown ______________________

____

High School Athletes:

Put check in front of sport or sports you played in high school or college. After names of sport, put Varsity, Jr. Varsity, or Freshman, and First String or Substitute.

_____ Football

_____ Basketball

_____ Baseball or Softball

_____ Track - running

_____ Track - field events

_____ Swimming

_____ Wrestling

_____ Weight lifting

Other ______________________

Check estimated size of high school or college.

High School	College	Location of
_____ 0 - 100	_____ 0 - 500	High School __________
_____ 100 - 400	_____ 500 - 1000	__________
_____ 400 - 800	_____ 1000 - 2000	College __________
_____ over 800	_____ over 2000	__________

Figure 16. Subject Score Card (Side Two)

35. Athletic Experience Scale. A score of "1" was assigned if the subject had participated as varsity first string, varsity substitute, or J.V. first string in any sport; a score of "0" was assigned if he indicated no such participation.
36. Athletic Versatility Index. The number of different sports in which the subject participated in high school or college, or organized club; all levels of participation were counted.
37. Football Experience. A score of "1" was given if the subject participated on the high school varsity (first string or substitute) or on the J.V. (first string); a score of "0" was given if he did not show this participation in football.
38. Basketball Experience. Same scoring as for football.
39. Baseball Experience. Same scoring as for football.
40. Track (Running) Experience. Same scoring as for football.
41. Track (Field) Experience. Same scoring as for football.

Actually, we realized that variables 35-41 were subject to distortion by the subjects and we had no idea of their reliability. Besides, how do you compare first string varsity in a small country school with first string varsity in a school of 3000 students? We tried different "scaling techniques" for this (e.g. more weight for 1st string in a large city than for 1st string in a small city, etc.), but abandoned these in favor of the simpler scheme described above. The purpose of these supplementary variables was to see if there were relationships with the strength factors identified.

RESULTS

Distribution statistics and test reliabilities

Table 1 presents the means and standard deviations of all tests administered at the Great Lakes Naval Training Center. Complete frequency distributions were tabulated for each test. For practically all the tests these closely approximated normal distributions. The test reliabilities are based on various pretest samples and are adequate for our purposes. Many of these reliabilities are exceptionally high even for the brief, time-limit tests. This is an important finding, in its own right, and indicates that stable measures of performance can be obtained from such tests.

The average age of these 201 subjects was 18 years, 3 months (Standard Deviation = 1 year, 3 months). Their average height was 5 feet, 10 inches (Standard Deviation = 2.8 inches). Their average weight was 150.6 pounds (Standard Deviation = 20.3 lbs.). The mean General Classification Test score for our subjects was 51.9,

TABLE 1

Means, Standard Deviations, and Reliabilities of Test Scores

(N = 201)

	Test Variable	Units*	Mean	S.D.	Reliability**
1.	Leg Lifts	number/20 sec.	12.58	3.50	.84
2.	Push-ups (in 15 sec.)	number/15 sec.	7.58	3.86	.76
3.	Reverse Sit-ups	number/20 sec.	17.44	3.78	.76
4.	Deep Kneebends	number/30 sec.	24.57	4.57	.85
5.	Sit-ups	number/30 sec.	16.89	4.15	.72
6.	Squat Thrusts	number/30 sec.	19.20	4.46	.70
7.	Pull Weights-Arms	number/20 sec.	26.30	11.34	.80
8.	Hand Grip	pounds force	119.32	18.36	.91
9.	Push Weights-Arms	number/20 sec.	22.77	3.58	.90
10.	Arm Pull-Dyna.	pounds force	182.23	29.68	.83
11.	Push Weights-Feet	number/20 sec.	22.22	3.46	.78
12.	Trunk Pull-Dyna.	pounds force	116.10	34.61	.67
13.	Rope Climb	feet/6 sec.	4.55	2.35	.80
14.	Dips (in 10 sec.)	number/10 sec.	3.97	2.19	.92
15.	Vertical Jump	inches	18.43	2.66	.90
16.	Dips (to limit)	number	6.66	4.46	.91
17.	Standing Broad Jump	inches	82.94	8.73	.90
18.	Leg Raiser	seconds held	72.35	35.63	.71
19.	10 Yard Dash	seconds	2.37	.14	.62
20.	Bent Arm Hang	seconds	35.21	13.54	.77
21.	50 Yard Dash	seconds	7.00	.45	.86
22.	Chins (to limit)	number	5.96	3.61	.93
23.	Shuttle Run	seconds	20.68	1.08	.85
24.	Chins (in 20 sec.)	number/20 sec.	3.88	2.00	.95
25.	Medic. Ball Put (stand.)	feet	20.03	2.73	.70
26.	Hold Half Sit-up	seconds held	37.61	21.81	.88
27.	Medic. Ball Put (sit.)	feet	6.04	1.41	.73
28.	Hold Half Push-up	seconds held	39.54	21.98	.85
29.	Softball Throw	feet	150.31	26.58	.93
30.	Push-ups (to limit)	number	12.31	7.99	.88

*See Test Descriptions for complete administration procedures.

**Test-retest reliabilities from pretest or previous samples.

TABLE 2

Intercorrelations* Among the Tests and the Other Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1. Leg Lifts	00	38	16	23	22	27	18	06	26	13	24	16	31	40	27	32	35	31	29	33	37	30	28	36	20	38	27	24	28	37	-31	-16	-15	-08	14	14	10	15	21	08	05
2. Push-ups (in 15 sec.)	38	00	17	27	35	42	19	13	43	21	35	02	45	58	41	51	44	21	40	51	51	53	47	55	28	31	19	58	26	71	-34	-28	-07	-07	00	13	-10	04	-03	07	14
3. Reverse Sit-ups	16	17	00	10	00	09	19	04	23	02	22	06	16	23	14	20	18	-01	20	10	23	13	24	18	19	-01	07	-02	21	10	-24	-07	02	00	15	10	12	09	03	09	05
4. Deep Kneebends	23	27	10	00	19	06	16	-02	25	00	24	-04	32	37	22	39	27	17	29	19	25	28	28	30	05	12	11	19	14	27	-33	-22	09	-01	-01	02	-02	06	-01	00	04
5. Sit-ups	22	35	00	19	00	24	20	04	25	04	20	00	31	33	29	26	37	23	40	29	39	30	36	33	15	35	20	34	32	24	-13	-17	-02	-04	10	17	00	05	07	14	04
6. Squat Thrusts	27	42	09	06	24	00	04	06	31	14	27	02	34	34	18	33	32	18	18	34	32	34	34	36	21	16	15	37	20	37	-16	-17	-03	05	04	20	-03	04	10	09	05
7. Pull Weights-Arms	18	19	19	16	20	04	00	25	56	26	38	22	07	25	24	18	19	12	24	14	21	11	25	19	29	12	38	20	17	13	-04	23	09	10	18	21	23	10	03	15	12
8. Hand Grip	06	13	04	-02	04	06	25	00	45	55	20	41	08	19	22	16	12	-04	11	-02	13	06	04	08	51	06	28	07	22	17	25	49	15	-01	11	11	04	-03	-05	08	13
9. Push Weights-Arms	26	43	23	25	25	31	56	45	00	39	57	25	30	50	31	50	32	22	30	22	36	34	29	39	48	12	38	34	35	45	-13	26	03	00	17	18	19	09	07	10	12
10. Arm Pull, Dyna.	13	21	02	00	04	14	26	55	39	00	31	40	11	12	23	13	17	01	14	15	18	08	10	15	54	06	26	15	25	15	23	39	09	-07	10	17	13	-01	04	10	14
11. Push Weights-Feet	24	35	22	24	20	27	38	20	57	31	00	23	21	34	24	32	26	22	15	19	19	19	13	20	35	11	23	19	28	33	-10	15	13	16	11	13	10	06	07	11	09
12. Trunk Pull, Dyna.	16	02	06	-04	00	02	22	41	25	40	23	00	-04	00	10	-01	20	-15	09	-10	03	-09	-03	-07	37	18	31	-07	24	01	32	42	07	-02	12	14	20	01	06	07	10
13. Rope Climb	31	45	16	32	31	34	07	08	30	11	21	-04	00	65	48	58	46	22	43	57	58	72	52	71	15	24	03	38	24	48	-43	-48	-10	-11	01	09	-05	-04	-05	06	05
14. Dips (in 10 sec.)	40	58	23	37	33	34	25	19	50	12	34	00	65	00	46	73	48	31	44	55	57	63	51	66	23	30	12	47	29	64	-43	-34	-10	-09	07	17	-03	05	-01	07	10
15. Vertical Jump	27	41	14	22	29	18	24	22	31	23	24	10	48	46	00	41	60	03	56	30	69	38	61	46	33	13	27	22	42	31	-19	-21	04	-07	24	22	10	15	05	26	17
16. Dips (to limit)	32	57	20	39	26	33	18	16	50	13	32	-01	58	73	41	00	41	31	37	44	52	57	46	56	20	24	03	40	23	56	-41	-32	-03	-01	03	06	-10	04	-01	13	05
17. Standing Broad Jump	35	44	18	27	37	32	19	12	32	17	26	20	46	48	60	41	00	08	58	38	68	43	69	50	31	19	27	32	44	34	-16	-23	02	-09	12	19	06	10	10	18	08
18. Leg Raiser	31	21	-01	17	23	18	12	-04	22	01	22	-15	22	31	03	31	08	00	14	38	15	32	15	20	05	32	-01	27	14	28	-38	-20	-05	04	00	01	-07	11	09	-02	02
19. 10 Yard Dash	29	40	20	29	40	18	24	11	30	14	15	09	43	44	56	37	58	14	00	38	69	40	67	44	29	22	22	29	40	31	-25	-24	-03	-07	19	20	01	14	05	23	11
20. Bent Arm Hang	33	51	10	19	29	34	14	-02	22	15	19	-10	57	55	30	44	38	38	38	00	43	65	40	64	04	40	-03	57	16	47	-32	-48	-10	-10	01	22	-06	11	03	05	07
21. 50 Yard Dash	37	51	23	25	39	32	24	13	36	18	19	03	58	57	69	52	68	15	69	43	00	53	80	61	31	29	24	37	48	38	-24	-32	-05	-09	28	24	12	15	12	31	17
22. Chins (to limit)	30	53	13	28	30	34	11	06	34	08	19	-09	72	63	38	57	43	32	40	65	53	00	52	85	09	19	05	52	23	58	-42	-45	03	-05	00	05	-07	-03	-03	01	06
23. Shuttle Run	28	47	24	28	36	34	25	04	29	10	13	-03	52	51	61	46	69	15	67	40	80	52	00	57	21	21	21	39	50	34	-31	-38	-06	-05	20	22	09	20	13	23	07
24. Chins (in 20 sec.)	36	55	18	30	33	36	19	08	39	15	20	-07	71	66	46	56	50	20	44	64	61	85	57	00	20	23	15	53	32	55	-38	-40	-03	-15	04	13	03	00	-02	03	09
25. Medic. Ball Put (stand.)	20	28	19	05	15	21	29	51	48	54	35	37	15	23	33	20	31	05	29	04	31	09	21	20	00	07	38	16	43	21	17	39	04	-06	16	16	14	05	01	14	10
26. Hold Half Push-up	38	31	-01	12	35	16	12	06	12	06	11	18	24	30	13	24	19	32	22	40	29	19	21	23	07	00	11	29	21	27	-19	-17	-09	-13	01	11	-04	05	07	05	06
27. Medic. Ball Put (sit.)	27	19	07	11	20	15	38	28	38	26	23	31	03	12	27	03	27	-01	22	-03	24	05	21	15	38	11	00	15	32	14	18	32	12	-07	23	14	16	14	11	13	12
28. Hold Half Push-up	24	58	-02	19	34	37	20	07	34	15	19	-07	38	47	22	40	32	27	29	57	37	52	39	53	16	29	15	00	19	54	-28	-23	02	05	00	15	-02	05	03	03	08
29. Softball Throw	28	26	21	14	32	20	17	22	35	25	28	24	24	29	42	23	44	14	40	16	48	23	50	32	43	21	32	19	00	17	-09	04	-03	-17	23	22	15	21	17	14	12
30. Push-ups (to limit)	37	71	10	27	24	37	13	17	45	15	33	01	48	64	31	56	34	28	31	47	38	58	34	55	21	27	14	54	17	00	-33	-25	-01	04	-01	09	-07	-04	-08	-01	07
31. Height	-31	-34	-24	-33	-13	-16	-04	25	-13	23	-10	32	-43	-43	-19	-41	-16	-38	-25	-32	-24	-42	-31	-38	17	-19	18	-28	-09	-33	00	57	07	00	06	10	09	-03	-03	08	04
32. Weight	-26	-28	-07	-22	-17	-17	23	49	26	39	15	42	-48	-34	-21	-32	-23	-20	-24	-48	-32	-45	-38	-40	39	-17	32	-23	04	-25	57	00	21	01	06	02	18	-02	01	-02	05
33. Age	-15	-07	02	09	-02	-03	09	15	03	09	13	07	-10	-10	04	-03	02	-05	-03	-10	-05	03	-06	-03	04	-09	12	02	-03	-01	07	21	00	15	09	10	02	07	11	03	04
34. Gen. Classif. Test	-08	-07	00	-01	-04	05	10	-01	00	-07	16	-02	-11	-09	-07	-01	-09	04	-07	-10	-09	-05	-05	-15	-06	-13	-07	05	-19	04	00	01	15	00	03	-07	01	-10	-08	02	02
35. Athletic Exper. Scale	14	00	15	-01	10	04	18	11	17	10	11	12	01	07	24	03	12	00	19	01	28	00	20	04	16	01	23	00	23	-01	06	06	09	03	00	67	60	64	42	66	60
36. Athletic Versat. Index	14	13	10	02	17	20	21	11	18	17	13	14	09	17	22	06	19	01	20	22	24	05	22	13	16	11	14	15	22	09	10	02	10	-07	67	00	48	49	43	45	41
37. Football Experience	10	-10	12	-02	00	-03	23	04	19	13	10	20	-05	-03	10	-10	06	-07	01	-06	12	-07	09	03	14	-04	16	-02	15	-07	09	18	02	01	60	48	00	23	23	24	25
38. Basketball Experience	15	04	09	06	05	04	10	-03	09	-01	06	01	-04	05	15	04	10	11	14	11	15	-03	20	00	05	05	14	05	21	-04	-03	-02	07	-10	64	49	23	00	50	34	23
39. Baseball Experience	21	-03	03	-01	07	10	03	-05	07	04	07	06	-05	-01	05	-01	10	09	05	03	12	-03	13	-02	01	07	11	03	17	-08	-03	01	11	-08	42	43	23	50	00	11	05
40. Track (Run.) Experience	08	07	09	00	14	09	15	08	10	10	11	07	06	07	26	13	18	-02	23	05	31	01	23	03	14	05	13	03	14	-01	08	-02	03	02	66	45	24	34	11	00	54

with a Standard Deviation of 8.0. Since the test is standardized to give a mean of 50 and a standard deviation of 10, it can be seen that our subjects represent a good cross section of Navy recruits.

Test intercorrelations.

Table 2 presents the matrix of correlations among the 41 variables; this includes the 30 physical fitness tests, height, weight, age, General Classification Test score, and the seven "athletic experience" indices described earlier.

It can be seen that there is no general "athletic proficiency" factor or general "strength" factor, since the correlations are not uniformly high. Rather, there are several groupings of high correlations indicating a number of separate factors.

Factor Analysis

The correlation matrix was factored by the centroid method programmed for an IBM 650 computer. The seven factor centroid solution is presented in Table 3. Rotation to a simple structure was accomplished using Kaiser's Verimax analytical solution, also programmed for the IBM 650. The resulting rotated matrix is presented in Table 4. The factors will be interpreted for meaningfulness from the loadings of the tests. We will describe each factor in turn. Tests with loadings of .30 or higher are listed for each factor.

Factor I is best defined by tests originally included to measure Dynamic Strength.

Variable	Name	Loading
22	Chins (to limit)	.81
24	Chins (in 20 sec.)	.78
30	Push-ups (to limit)	.74
20	Bent Arm Hang	.73
14	Dips (in 10 sec.)	.70
2	Push-ups (in 15 sec.)	.68
28	Hold Half Push-up	.68
13	Rope Climb	.67
16	Dips (to limit)	.63
6	Squat Thrusts (in 30 sec.)	.67
21	50 Yard Dash	.44
23	Shuttle Run	.39
9	Push Weights-Arms (in 20 sec.)	.45
17	Standing Broad Jump	.35
18	Leg Raiser	.35
1	Leg Lifts (in 20 sec.)	.32
5	Sit-ups (in 30 sec.)	.31
15	Vertical Jump	.30
26	Hold Half Sit-up	.30
32	Weight	-.43
31	Height	-.39

TABLE 3

Centroid Factor Loadings*

	Variable	I	II	III	IV	V	VI	VII
1.	Leg Lifts	52	09	-05	-08	-22	19	-18
2.	Push-ups (in 15 sec.)	68	29	-20	-07	09	08	-08
3.	Reverse Sit-ups	27	-08	07	05	-10	-26	-11
4.	Deep Kneebends	37	17	-03	-04	-22	-25	-09
5.	Sit-ups	46	14	03	06	-15	13	09
6.	Squat Thrusts	44	11	-11	-10	05	15	11
7.	Pull Weights-Arms	41	-31	-20	08	-22	-23	17
8.	Hand Grip	27	-40	-43	27	20	04	-12
9.	Push Weights-Arms	62	-25	-41	07	-08	[illegible]	04
10.	Arm Pull, Dyna.	34	-38	-38	22	22	[illegible]	-08
11.	Push Weights-Feet	46	-22	-35	-09	-22	-18	-07
12.	Trunk Pull. Dyna.	17	-45	-25	23	-05	16	-15
13.	Rope Climb	64	43	-02	07	20	-13	-05
14.	Dips (in 10 sec.)	74	32	-16	-05	08	-14	-11
15.	Vertical Jump	65	02	19	32	09	-12	-06
16.	Dips (to limit)	65	30	-18	-08	04	-22	-16
17.	Standing Broad Jump	67	12	14	32	-06	03	06
18.	Leg Raiser	32	21	-13	-31	-25	08	-06
19.	10 Yard Dash	-64	-13	-23	-32	09	05	03
20.	Bent Arm Hang	59	41	-07	-19	13	17	09
21.	50 Yard Dash	-18	-17	-27	-30	-07	06	-03
22.	Chins (to limit)	66	45	-14	-05	19	-14	21
23.	Shuttle Run	-71	-21	-14	-29	05	06	-15
24.	Chins (in 20 sec.)	72	38	-09	07	23	-09	23
25.	Medic. Ball Put (stand.)	44	-38	-29	35	08	12	-15
26.	Hold Half Sit-up	38	17	-06	-07	-16	35	-16
27.	Medic. Ball Put (sit.)	36	-34	-14	23	-17	08	13
28.	Hold Half Push-up	54	26	-21	-18	07	15	28
29.	Softball Throw	54	-15	12	31	-15	17	-10
30.	Push-ups (to limit)	60	30	-35	-20	13	-03	-06
31.	Height	-34	-50	-09	24	24	27	18
32.	Weight	-20	-72	-41	23	-06	09	05
33.	Age	01	-22	-09	-06	-07	-13	17
34.	Gen. Classif. Test	-08	-05	-11	-17	-05	-26	10
35.	Athletic Exper. Scale	39	-60	51	-34	17	-08	02
36.	Athletic Versat. Index	44	-44	33	-29	17	16	14
37.	Football Experience	20	-48	23	-09	06	-08	15
38.	Basketball Experience	29	-35	40	-30	-13	16	05
39.	Baseball Experience	20	-27	29	-23	-23	26	19
40.	Track (Run.) Experience	33	-36	38	-15	23	-09	-12
41.	Track (Field) Experience	29	-34	20	-24	30	-08	-15

* Rounded to two places and decimals omitted.

TABLE 4

Rotated Factor Loadings*

	Variable	I DS	II SS	III ES	IV TS	V WB	VI AE-G	VII AE-S	h^2
					Factors**				
1.	Leg Lifts	32	13	23	47	-01	08	00	40
2.	Push-ups (in 15 sec.)	68	15	23	22	-04	05	-09	60
3.	Reverse Sit-ups	04	04	26	06	20	20	-16	18
4.	Deep Kneebends	25	-08	25	21	25	04	-21	28
5.	Sit-ups	31	05	33	23	03	-02	15	28
6.	Squat Thrusts	45	11	11	14	00	40	14	27
7.	Pull Weights-Arms	11	33	22	08	50	10	07	44
8.	Hand Grip	09	72	03	-09	05	06	-09	55
9.	Push Weights-Arms	38	51	21	11	44	12	-06	67
10.	Arm Pull, Dyna.	16	71	03	-02	-04	08	03	54
11.	Push Weights-Feet	25	35	08	26	43	13	12	47
12.	Trunk Pull, Dyna.	-13	59	06	13	04	06	02	39
13.	Rope Climb	67	-03	41	-01	06	06	20	66
14.	Dips (in 10 sec.)	70	09	33	16	08	12	-23	71
15.	Vertical Jump	30	18	64	-02	-01	22	-06	58
16.	Dips (to limit)	63	05	27	17	13	12	-30	63
17.	Standing Broad Jump	35	15	66	11	00	05	08	60
18.	Leg Raiser	35	-10	-02	43	12	00	-02	33
19.	10 Yard Dash	28	07	70	12	-01	10	-01	59
20.	Bent Arm Hang	73	-06	16	18	12	03	08	61
21.	50 Yard Dash	44	07	75	02	-05	20	03	80
22.	Chins (to limit)	81	-05	29	-07	10	-03	-04	76
23.	Shuttle Run	39	-04	77	04	01	11	12	77
24.	Chins (in 20 sec.)	78	04	40	-10	04	00	02	79
25.	Medic. Ball Put (stand.)	09	71	25	06	01	09	-04	59
26.	Hold Half Sit-up	30	09	13	45	-18	-03	05	35
27.	Medic. Ball Put (sit.)	02	44	26	11	22	02	20	36
28.	Hold Half Push-up	68	05	08	12	07	-05	21	54
29.	Softball Throw	09	32	54	25	-06	13	10	49
30.	Push-ups (to limit)	74	14	04	17	07	04	-17	63
31.	Height	-39	42	-21	-31	-15	-04	32	59
32.	Weight	-43	70	-23	-08	24	-04	14	81
33.	Age	-04	09	-06	-06	28	06	10	11
34.	Gen. Classif. Test	01	-08	-16	-08	29	03	-05	13
35.	Athletic Exper. Scale	-03	05	13	-01	11	89	32	92
36.	Athletic Versat. Index	15	13	08	-06	01	45	64	65
37.	Football Experience	-10	14	10	-09	19	45	28	36
38.	Basketball Experience	-04	-05	10	27	05	51	38	50
39.	Baseball Experience	-05	04	07	29	07	27	48	40
40.	Track (Run.) Experience	02	07	17	-05	-04	66	09	48
41.	Track (Field) Experience	10	13	-01	-06	-03	63	02	43

*Factor loadings have been rounded to two places and decimals omitted.

**Factors are identified as follows: I, Dynamic Strength; II, Static Strength; III, Explosive Strength; IV, Trunk Strength; V, Weight Balance; VI, Athletic Experience-General; VII, Athletic Experience-Specific.

The best measures of this factor turn out to be tests in which the arms are required repeatedly or continuously, to move or support the weight of the body. This is true of all tests with loadings over .60. However, the factor extends beyond arm muscle groups to tests involving legs (e.g. the runs and jump tests) and trunk muscles (e.g. Sit-up tests, Leg Lift and Leg Raiser tests). The critical aspect of this factor appears to be the requirement that the muscular force be repeated or exerted continuously, with a consequent progressive decrement in the force which can be exerted.

Weight and height load negatively on this factor. This indicates that subjects with more body mass are less likely to score high on this factor. These results also show the factor common to the "endurance" and "time limit" strength tests. Thus, "chinning as fast as possible in 20 seconds" depends on the same factor as "holding the chin position (bent arm hang) as long as possible" or "doing as many chins as possible." No separate factors emphasizing "endurance" versus "speed" in such tests were found. Furthermore, there was no consistent advantage of one procedure over the other ("time limit" vs. "endurance limit") in how well this factor is measured; loadings of the same tests given under both conditions do not differ significantly (see, e.g., the different variations of chins, push-ups, and dips). Additionally, no separate arm flexor and extensor factors appeared.

The results also extend this factor from tests requiring repeated muscle strain (chins, dips, push-ups) to tests requiring prolonged continuous support of the body (Bent Arm Hang, Hold Half Push-ups, Hold Half Sit-ups). We also see that this factor extends to more complex performance tasks such as Rope Climb and running tests. As it turns out, individual differences in running tests are better accounted for by another factor, but at least some of the variance in such performance tests are accounted for by this Dynamic Strength factor.

This factor was involved, in some degree in 19 out of the 30 tests and, hence, is the most general of our strength factors.

Factor II is confined to those tests in which the subject must exert force against either a dynamometer, a relatively heavy weight, or some fairly immovable or heavy object. Without exception, all of the tests involving either dynamometers or weights fall on this factor.

Variable	Name	Loading
8	Hand Grip	.72
10	Arm Pull-Dynamometer	.71
25	Medicine Ball Put - Standing	.71
32	Weight	.70
12	Trunk Pull-Dynamometer	.59
9	Push Weights-Arms (in 20 sec.)	.51
27	Medicine Ball Put - Sitting	.44
31	Height	.42
11	Push Weights-Feet (in 20 sec.)	.35
7	Pull Weights-Arms (in 20 sec.)	.33
29	Softball Throw	.32

Clearly, this factor is the Static Strength factor hypothesized. The most important finding is the generality of this factor to different muscle groups (hand, arm, back, shoulder, legs) and to different kinds of tasks. The factor extends from the capacity to apply force against a practically immovable object (dynamometers), to capacity to lift or push weights with the arms or feet. It is general to extensor and flexor muscle involvement.

The common, critical feature of this factor is the requirement that a maximum force be exerted for a brief period of time where the force is exerted continuously up to this maximum. In contrast to Dynamic Strength the force exerted is against external objects, rather than in supporting or propelling the body's own weight. Where weight and height are negatively related to Dynamic Strength, they are positively related to Static Strength; the relation between body weight and performance on this factor is especially high.

The presence on this factor of the Medicine Ball - Put tests was not expected, but is not inconsistent with the present interpretation. The Medicine Ball is unwieldy, could not be "put" very far, and we required this task to be carried out from a static position with very little leverage possible. It is possible that the heavier the object to be "put" or "thrown" the higher will be the loading on this factor. (Softball Throw loaded only .32 on this factor.) It is also of interest that the training programs of our champion shot-putters consists in a considerable amount of weight lifting. Thus, muscle mass seems a critical component of this strength factor, but not of the other strength factors identified.

The Static Strength factor is the factor most people think of as the "brute strength" of the "strong man." Furthermore, many test batteries of physical proficiency place considerable emphasis on different tests of Static Strength. The independence of this factor from the other strength factors, together with the greater practical implications of these other factors in significant human activities, would argue against such overemphasis on tests of Static Strength.

Factor III contains the tests included to emphasize Explosive Strength. The factor also includes all the "running" tests and this, too, confirms previous findings.

Variable	Name	Loading
23	Shuttle run	.77
21	50 Yard Dash	.75
19	10 Yard Dash	.70
17	Standing Broad Jump	.66
15	Vertical Jump	.64
29	Softball Throw	.54
13	Rope Climb (in 6 sec.)	.41
24	Chins (in 20 sec.)	.40
5	Sit-ups (in 30 sec.)	.33
14	Dips (in 10 sec.)	.33

The Explosive Strength factor emphasizes the ability to expend a maximum of energy in one explosive act. The common feature of tests with highest loadings on this factor is that one is required to jump or to project oneself or to project some object as far or as high as possible. The factor is distinguished from the other strength factors in that it requires mobilization of energy for a burst of effort, rather than continuous strain, stress, or repeated exertion. In fact, an alternate factor name is "Energy Mobilization."

Apparently, this is the main factor accounting for individual differences in dashes and sprints. Presumably speed in these events is dependent on effective mobilization of force against the ground in propelling oneself forward. It was assumed that this factor would account for more of the variance in the 10 Yard Dash, than in the 50 Yard Dash and Shuttle Run. Primarily, this would be due to the increased importance of the initial "push-off" in the shorter run. Since this factor was found important in all three runs, the assumption is that it contributes in the "push-off" of each step of the run.

The finding that this factor is independent of particular muscle groups is important. Although somewhat better measured by "leg" tests (jumps, dashes), the factor extends to arm-shoulder tests as well (e.g., Soft-Ball Throw). It is also interesting that certain of the tests found loaded on the Dynamic Strength factor, have secondary loadings on the Explosive Strength factor. These turn out to be those tests involving the same muscles, but given under time-limit conditions. Thus, instructing the subject to perform "as rapidly as possible" is more likely to bring into play Explosive Strength; this is not as likely to happen where the subject proceeds at his own pace until he cannot do any more chins, dips, etc. This seems entirely reasonable when one pictures the tasks performed under each of these two conditions. This also fits the notion of "Engergy Mobilization" involvement, which would be more important in the time-limit versions of these tests. This indicates that the "endurance limit" condition is likely to provide a "more pure" measure of Dynamic Strength in tests like Chins and Dips, where "time-limit" administration of Chins and Dips will measure Dynamic Strength and secondarily, Explosive Strength.

This study finds no evidence for separate arm and leg Explosive Strength factors. Such factors found in previous research were highly correlated with each other and did yield a general Explosive Strength factor on further factoring. The loadings of our run tests also confirm our suspicion that factors called "Velocity" and "Power" in previous studies are really the same as this Explosive Strength factor.

Factor IV is confined to three tests which emphasize the strength of the trunk muscles.

Variable	Name	Loading
1	Leg Lifts (in 20 sec.)	.47
26	Hold Half Sit-up	.45
18	Leg Raiser	.43
31	Height	-.31

All of these tests have secondary loadings on the more general Dynamic Strength factor. Apparently there is a second Dynamic Strength factor specific to the trunk muscles, and particularly to the abdominal muscles. This confirms some previous findings (Hempel and Fleishman, 1955; Phillips, 1949.) This factor is labeled, simply, Trunk Strength.

Two tests emphasizing trunk muscle involvement did not have loadings as high as .30 on this factor. One of these (Sit-ups (in 30 secs.)) had a loading of .23; apparently the "Hold Half Sit-up" counterpart, with a loading of .45, is a better measure of this factor. The "Reverse Sit-up" test did not load at all on this factor. Of course, in this test the abdominal muscles are not mainly involved (see test description). On further reflection, the test may be more a measure of one of the Flexibility factors found elsewhere (see Fleishman, Thomas, and Munroe, 1961).

Since Height loads -.31 on this factor, it appears that taller subjects are somewhat less likely to score high on the Trunk Strength factor.

Factor V is a narrow factor restricted to just those tests involving the manipulation of weights.

Variable	Name	Loading
7	Pull Weights-Arms (in 20 sec.)	.50
9	Push Weights-Arms (in 20 sec.)	.44
11	Push Weights-Feet (in 20 sec.)	.43

A tentative interpretation is that this factor involves some skill in balancing the weights properly. If the weights are not balanced properly, a disproportionate strain is placed on one limb. It is unlikely that this factor represents an important strength factor and for the present it is labeled Weight Balance.

Factors VI and VII contain no test variables, but only "athletic experience" variables. These "experience" variables were derived from the "athletic history" questionnaire filled out by the subjects (see Procedure). This was an attempt to find relationships between the present physical proficiency factors and such sports participation. The reader may have noted that our strength factors have not extended to these sports participation indices. Part of the reason may be the heterogeneous background of our subjects and the limitations in these indices which we described earlier. Then again, "sports participation" is not a very direct measure of sports proficiency. And, some subjects scoring high on the strength factors may have gone to schools without many sports opportunities. In any case, there are many possible reasons which would artificially deflate possible correlations between our "participation" and "proficiency" variables. We included the questionnaire for purely exploratory purposes. Now that the strength factors are identified, there are more direct ways of investigating their relationships with athletic proficiency.

For the present, let us list the two factors found confined to the questionnaire responses. Factor VI is the more general of the two factors and is labeled "Athletic Experience-General."

Variable	Name	Loading
35	Athletic Experience Scale	.89
40	Track (Running) Experience	.66
36	Athletic Versatility Index	.64
41	Track (Field) Experience	.63
38	Basketball Experience	.51
37	Football Experience	.45
6	Squat Thrusts (in 30 sec.)	.40

Among the highest loadings are the indices reflecting general participation and number of different sports participated in. The only test loaded on this factor is Squat Thrusts and it is interesting to note that this test is similar to a conditioning exercise commonly used in training for these sports.

Factor VII represents a second cluster of experience variables, which we have labeled Athletic Experience--Specific.

Variable	Name	Loading
39	Baseball Experience	.48
36	Athletic Versatility	.45
38	Basketball Experience	.38
35	Athletic Experience	.32
31	Height	.32

Apparently, there tend to be two primary patterns of sports participation. One involving the Football-Basketball-Track combination (see Factor VI) and the other a Basketball-Baseball combination. Note the loading of height on this factor.

DISCUSSION

The main findings appear to center on the confirmation of the three primary strength factors: Dynamic Strength, Static Strength, and Explosive Strength. Equally important is the relative independence of these three factors. While Dynamic Strength is the more general of the three, the correlation between these three factors is very low. Some tests involving Dynamic Strength, also involve Explosive Strength. But there are "pure" measures of each factor. (Thus, Softball Throw loads on Explosive Strength and not Dynamic Strength, while Bent Arm Hand and Push-ups are pure measures of Dynamic Strength). Our rotated factor matrix (Table 4) provides a basis for selecting tests which provide "purest" measures of each factor (high loading on one factor, close to zero loading on the other factors).

We should not ignore Factor IV, Trunk Strength. Although all tests on this factor also load on the more general Dynamic Strength factor, comprehensive batteries of strength tests should include a separate measure of Trunk Strength. The three tests loaded on this factor appear to be equally useful for this purpose. In actual practice, however, it would be somewhat easier to standardize the administration of the Leg Lifts test (see test description, above).

The Reverse Sit-ups Test, different forms of which are popular in some of today's physical fitness test batteries, emerges as a highly specific test in our study. It does not load significantly on any of our strength factors. Either the test measures some limited kind of strength or it is more usefully considered a "flexibility" measure.

Of secondary interest are the relations of these tests with the non-test variables. The General Classification Test score did not load on any of these factors. Thus, the independence of general "intellectual level" and physical strength is confirmed. (There is neither a positive nor a negative correlation.) We have already discussed possible reasons why the athletic experience and strength factors were found unrelated here. Subsequent studies might make a more direct attack on this question. This would involve administering such tests to candidates for these sports, following up the athletic proficiency of these candidates, and validating the tests against subsequent performance. Our present results simply show that self reports of athletic history, from subjects of heterogeneous backgrounds, do not correlate with proficiency in strength tests. On the positive side, we did isolate two patterns of reported sports participation: a cluster representing football-basketball-track, as distinguished from basketball-baseball experience. This implies, that among our subjects, football players were more likely to have participated in basketball and track, than in basketball and baseball. Baseball players were more likely to have participated in basketball than in football.

Of some importance is the relation of height and weight to our factors. The main finding here is that these "size" variables are related differently to the four different strength factors. Subjects who are heavier and taller tend not to do quite as well on Dynamic Strength. On tests of Static Strength Weight seems especially important. Neither Weight nor Height relate to performance on Explosive Strength. Finally, there is some tendency for taller subjects not to do as well on Trunk Strength tests. These findings bear on the "size classifications" often used in tables of age norms for test performance. It is our feeling that these "corrections" may sometimes introduce more error than "adjustment." Our results show that no single size classification is related in the same way to different physical fitness factors, even within a limited area such as "strength."

Some final comments are in order regarding some of our original hypotheses. The main factors expected, did appear. However, no separate "endurance" factors or "speed factors" appeared. It does not seem necessary to provide separate measures of "muscle endurance" in the strength area. No such factor distinguishes performances carried to "limit" from shorter timed versions of these same tests. It appears that this kind of "endurance" and "dynamic strength" both depend on the same underlying ability factor. (This may be conceptualized in some terms of "physical energy," see below.) We were not able to include endurance tests involving prolonged activity such as distance runs. In retrospect it would have been useful to have included some variant of the 600 yard run-walk test. (This kind of test is believed related to "cardio vascular endurance" as distinguished from the "muscular endurance" we tried to isolate.) The extent to which such tests depend in our present strength factors remains to be seen.

The present study confirms the difficulty of isolating a separate "speed factor." Our running tests loaded on other common factors (Explosive and Dynamic Strength). There appears to be no general "speed factor" (see Fleishman, Thomas, & Munroe, 1961), independent of other common factors. (Incidentally, the finding that running tests are mainly "explosive strength" is consistent with recent high jump coaching practices; many track coaches (notabl the Russians), emphasize running speed in the high jump approach.)

The fact that no separate extensor and flexor factors appeared, is not surprising since both sets of muscles within the same limbs are likely to be exercised together in practice. More important is the finding of factors extending across different muscle groups. All three primary strength factors extend beyond arms to either legs or trunk muscles as well. This implies that a good deal of what we call strength depends on "central" factors. While we do not need to speculate farther on this, we may mention such possibilities as central nervous system involvement, responses to feedback mechanisms, heart and circulatory system development, etc. Our factor results are consistent with experimental findings, in which strength in one arm can be improved somewhat by prolonged exercise of the other arm.

Test Recommendations

Test recommendations for coverage of the four main strength factors are summarized in Table 5. These recommendations take into consideration the size of the factor loadings of each test on its main factor, and its low to zero loadings on other factors, the reliabilities of the individual tests, ease of standardization. In this latter connection we favored familiar tests to new ones, tests requiring no special equipment to more elaborate tests.

A minimal test battery, in the strength area, would employ one test from each factor. These four tests would reproduce most of the information derivable from all 30 of the present tests; that is, these tests would measure what it is that these 30 tests have in common. Presumably it is these common abilities that are most important since this is what should generalize to other tasks. However, it is also true that each test measures

Table 5

Recommended Test Batteries for Evaluation in the Strength Area

Factor Measured	Tests	Recommended Choice for Batteries of Different Lengths*						Factor Loading	Reliability
		4 Tests	5 Tests	6 Tests	7 Tests	8 Tests	9 Tests		
I Dynamic Strength	Chins (to limit)	x	x	x	x	x	x	.81	.93
	Push-ups (to limit)						x	.74	.88
II Static Strength	Hand Grip	x	x	x	x	x	x	.72	.91
	Arm Pull-Dyna.			x	x	x	x	.71	.83
III Explosive Strength	Shuttle Run <u>or</u> 50 Yard Dash	x	x	x	x	x	x	.77 .75	.85 .86
	Softball Throw		x	x	x	x	x	.66	.90
	Standing Broad Jump				x	x	x	.54	.93
IV Trunk Strength	Leg Lifts	x	x	x	x	x	x	.47	.84
	Hold Half Sit-up					x	x	.45	.88

*Addition of tests, in successive columns (from 4 to 9 test batteries), chosen to maximize the amount of information added by each new test.

something specific to itself. The extent of this specificity for each test is seen in the communality estimates (h^2 column of Table 4). The higher the communality the more we have "accounted for" performance on each test by our factors. Tests with low communalities (e.g. Reverse Sit-ups) indicate either that they tap narrow to highly specific abilities, or abilities not covered in our battery.

Inefficient test batteries are those with too many tests on one factor, and none from one or more of the other factors. The addition of more than one test per factor adds relatively little new information about a subject's strength, relative to the addition of tests from separate factors.

Shuttle Run, once assumed to measure a separate factor, adds relatively little to a battery with 50 yard dash; Push-ups added to Chins contributes little new information regarding a subject's Dynamic Strength. Although one test from each factor would be minimal, there are compelling reasons to choose more than one if time permits. This would provide higher reliability of each factor measure and would have the advantage of emphasizing certain specific features in each test along with the common factor. This is especially true in the case of Explosive and Static Strength, each of which can be measured by arm and leg tests, and in the case of Static Strength, by Trunk tests as well. (This is also true of Dynamic Strength, but arm tests are distinctly better there.) The longer batteries suggested in Table 5 provide for emphasis of specific features as well as for the common factors; hence, if there is time for more than one test of Explosive Strength Softball Throw is the next best addition, since it adds the arm-shoulder aspect to the leg emphasis already represented in Shuttle Run or 50 Yard Dash. (There is less reason for both 50 Yard Dash and Broad Jump than for 50 Yard Dash and Softball Throw; however, Broad Jump and Softball Throw would be an adequate substitution.)

It should be stressed that even the test batteries in Table 5 represent a much too limited coverage of physical proficiency. Elsewhere (Fleishman, Thomas, & Munroe, 1961) we have identified factors in the areas of Flexibility, Balance, Speed, and Coordination which need to be added to the present factors. The important point is that batteries in wide-spread use tend to emphasize only (or mainly) the strength area; and even in this area the Explosive Strength factor is typically represented by too many overlapping tests.

While the experimental tests helped clarify what many established tests measure, it is encouraging that our results confirm the superiority of many widely used tests (Broad Jump, Chins, Softball Throw). Our results do show that some established tests are much better than others. And it is nice to know that more elaborate devices are not needed to provide better measures in this area. In some cases, a new test version turns out to be a better measure than traditional ones (e.g. Leg Lifts over Sit-Ups in measuring Trunk Strength).

Some Theoretical Notions

Scientific investigation, even within a circumscribed area may proceed at various levels. In the present study, we are interested in understanding and describing performance in terms of observable behavior. From our correlational analysis it has been possible to conceptualize the strength area in terms of a limited number of descriptive "categories" or factors. These factors are useful, in themselves, in providing a framework for classifying the diversity of tests in this area, and for selecting tests to minimize overlap and provide adequate coverage of this area. We have purposely avoided physiological interpretations, which are beyond the present scope of our study and really not necessary for these purposes. Just for a moment, however, we would like to explore some notions at a more abstract level of analysis, which might be of interest to some readers. We should stress that this is a highly tentative analysis, in which further exploration and elaboration would be a research project in itself.

Our three primary factors are usefully considered as three parameters for describing individual strength. It appears to the author that these can be examined in terms of a physical model applied to muscle systems.

Briefly, a system of muscles may be very crudely compared with a gasoline engine. Like the engine, it takes in oxygen and hydrocarbons, combines them with the release of energy, and exhausts carbon dioxide and water. Both the muscle system and the engine, in simpliest terms, are mechanisms for converting chemical energy into mechanical energy. This conversion brings about relationships of scientific interest. The physical concepts of "force," "energy" and "power" are formulated by the engineer and physicist to express some of these relationships. Do these concepts relate to our factor analysis results?

While the analogy is not perfect, it does seem that Static Strength, Explosive Strength, and Dynamic Strength can be related to the physical parameters of Force, Energy, and Power, respectively. Let us first examine the relation between <u>Static Strength</u> and the concept of <u>Force</u>, applied to muscle systems. Force is an elusive physical concept defined by the physicist as that unit quantity which produces a unit acceleration on a unit mass ($F = M \times A$). As applied to engines the term is used in various ways. The "torque" of a gasoline engine comes close to a twisting force measurement. (Torque depends on the gear ratios built into the engine as well as on its energy producing capabilities.) Different lever systems vary in their force capabilities and this is a function of lever length, location of fulcra, etc. The tests of our Static Strength factor emphasize the lifting power of the muscles or the pounds of pressure which the muscles can exert.

Our Explosive Strength factor seems most related to the physical parameter of Energy. A unit of Energy, in physical terms is equal to a unit force moving through a unit distance. In other words, the amount of Energy in a system is equal to the distance (in feet) through which a force (in pounds) can be moved. It is measured in foot-pounds. We have given the Explosive Strength factor the alternate name of "Energy Mobilization," since tasks of measuring this factor require the effective release of energy in one explosive act ("Broad Jump," "Softball Throw"). The velocity (or kinetic energy) imparted is a function of the effective energy release. And we measure such muscular performances in terms of the distance (feet) through which a given mass (whether it is the body or some object) is propelled. The fact that our sprints are loaded on this factor is entirely consistent with this notion of "distance through which a force" can be moved.

Finally, the Dynamic Strength factor seems most analogous to the physical concept of Power. Power is defined in terms of the rate at which energy can be released and is measured in foot-pounds per second. (One horsepower is equal to that required to raise 33,000 lbs. at the rate of one foot per minute.) This Power is also defined in terms of the capacity for doing work (amount of work done per unit time). This in turn, is a function, of the stored energy in the system. The common requirement of all tests on the Dynamic Strength factor, is for the muscles involved to propel, support, or move the body repeatedly or to support it continuously over time. In those tasks which are timed (do as many chins as possible in 20 sec.), the rate of responding is most directly seen related to the power concept. The fact that such tasks correlate with their endurance counterparts ("Chins-to limit" and "Bent Arm Hang") is consistent with the Power notion, since these also depend on the rate of energy expenditure, and in turn on its conversion to mechanical energy from stored chemical energy in the muscle system. If an engine is producing energy at a given rate (i.e., it is producing a certain amount of power) it will be able to produce only a finite amount of energy before it breaks down. The same is true of muscle tissue. When given a heavy load or put under strain (e.g. more body mass, a greater distance, or a faster rate requirement) it will be able to produce a constant level of power only for a finite amount of time. Under that load it will be able to produce only so much energy, until it is no longer able to perform the task. This is the phenomenon known as fatigue.

The reader can sense the sketchy nature of these comments. There are alternate ways of conceptualizing these Strength factors. And we have chosen to eliminate physiological descriptions from our discussion. Rather we have tried to go directly from the language of physical mechanics to observable behavior, as measured by our performance tests.

SUMMARY

Thirty tests of various aspects of strength were administered to 201 Navy recruits. The test battery was specifically designed to test certain hypotheses about the nature of different strength factors. Factor analysis and objective, analytical factor rotations confirmed the importance of three general factors and a fourth more restricted factor. These factors were labeled Dynamic Strength, Explosive Strength, Static Strength, and Trunk Strength. The study provides recommendations for the tests most diagnostic of each factor. The results were discussed in terms of theoretical and practical issues regarding the nature and measurement of human strength.

The results of this study together with those completed in other areas of physical proficiency, have formed the basis for a more comprehensive physical fitness test battery. Research is nearly completed in which normative and comparative data have been collected on national school samples. These results will be reported, shortly, in subsequent reports.

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