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OCCUPATIONAL DIFFERENCES IN MUSCLE STRENGTH OF U.S. NAVY ENLISTED PERSONNEL

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Report No. 05-10

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Occupational Differences in Muscle Strength
of U.S. Navy Enlisted Personnel

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Report 05-10, supported by the United States Department of Defense under Work Unit 60109. The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. Approved for public release; distribution is unlimited. This research has been conducted in compliance with all applicable federal regulations governing the protection of human subjects in research.

Summary

Background

U.S. Navy occupations with heavy physical demands have high injury rates. Also, injuries are particularly common among inexperienced personnel. One reason could be that inexperienced personnel lack the strength to safely perform the tasks in physically demanding occupations. Over time, work tasks may provide on-the-job resistance training that matches strength to job demands.

Objective

This study tested the hypothesis that personnel in highly physically demanding jobs are stronger than those in less physically demanding jobs.

Methods

A strength test battery (biceps curl, shoulder press, latissimus pull-down, bench press, and leg press) was administered to 147 male U.S. Navy sailors. The first principal component of the strength test scores provided a general strength index. This index was used to test hypotheses without the problems associated with performing multiple significance tests. Occupations were divided into low demand ($n = 30$) and high demand ($n = 117$) groups based on ratings from experience senior enlisted personnel. Participants were divided into trained ($n = 118$) and untrained ($n = 29$) based on self-reported physical training history.

Analysis

Personnel in high-demand jobs were stronger than those in the low-demand jobs (effect size [ES] = 0.85; $p < .05$, one-tailed). The difference was larger for untrained personnel (ES = 1.32) than for trained personnel (ES = 0.38). Among untrained individuals, ES was reduced by controlling for age (ES = 1.22) and fat-free mass (FFM; ES = .73) but still was significant ($p < .001$).

Discussion

The pattern of strength differences was consistent with the hypothesis that occupational physical exertion provided informal resistance training. Recent meta-analyses have shown that resistance training produces larger effects for untrained individuals than for trained individuals. Among untrained sailors, the occupational difference in general strength was comparable to the effect of a modest (e.g., 2 sessions per week for 6 weeks) program of resistance training. Thus, strength gains may be one mechanism linking experience to reduced injury rates. If so, formal resistance training could reduce accident rates among the high-risk population of inexperienced personnel.

Accidental injury is a significant health problem within the military (Jones, 1999). The Secretary of Defense recently set a 50% reduction in injuries within 2 years as a current goal for the Department of Defense (U.S. Secretary of Defense, 2003). Programs to achieve this goal have been initiated (U.S. Undersecretary of Defense for Personnel and Readiness, 2003). Management of injury rates also is an element of Naval Force Health Protection for the 21st century (Kelly & Hanlon, 2004). One goal is to ensure that all naval forces are physically fit and fully capable of meeting the physical demands of their professions (Kelly & Hanlon, p. 4). A specific objective in support of this goal is to protect naval personnel from occupational injury (Kelly & Hanlon, p. 4).

Injury rates are the product of a complex pattern of causal factors. On one hand, the risk of injury is influenced by task attributes and environmental factors. On the other hand, the risk of injury is influenced by characteristics of the people who engage in potentially risky activities whether on duty or off.

Given the complex causal processes underlying accidental injury rates, injury reduction goals are not likely to be reached by some general solution that applies to all people and all situations. Instead, opportunities for injury reduction in specific populations in particular settings must be identified and exploited.

This report presents evidence that brief resistance training programs for personnel entering physically demanding U.S. Navy occupations could be one method of reducing injury rates. U.S. Navy personnel in physically demanding enlisted occupations have high hospitalization rates for injury and musculoskeletal disease (Vickers & Hervig, 1998, 1999; Vickers, Hervig, & White, 1997). Historically, injuries have been most frequent during the first few months on the job (Helmkamp & Bone, 1987). One possible explanation is that performing job-related tasks provides a training stimulus that decreases the risk of injury by increasing muscle strength.

Strength gains would reduce injury rates by protecting against overexertion. Overexertion, an established cause of occupational injuries (Bernard, 1997), is most likely when occupational demands exceed the strength of an average job incumbent (Chaffin, Herrin, & Keyserling, 1978). In this context, the high injury rates in some occupations suggest that required job-related exertions approach the maximal strength of at least some incumbents.

The tasks that increase the risk of injury might also have positive effects. If these tasks can be performed safely, the exertion required to perform them is akin to the exertions that produce strength gains in resistance training (McArdle, Katch, & Katch, 2001). In fact, task simulations have been successfully employed as strength training stimuli (Genaidy, 1991). Physically demanding occupational tasks therefore may have both positive and negative effects.

The above reasoning suggests that performing occupational tasks could provide informal resistance training. The effects of this training would be most evident among U.S. Navy enlisted personnel in physically demanding occupations. The temporal pattern of decreasing injury rates as personnel acquire more experience (Helmkamp & Bone, 1987) is consistent with this suggestion. High injury rates are observed in inexperienced personnel because occupational tasks involve fixed demands. Tasks are not progressively modified to begin with easy work and then increase demands as would be done in formal progressive resistance training. Therefore, weaker individuals in high-demand occupations are at risk until they become strong enough to safely perform the demanding tasks.

If occupational tasks provide on-the-job resistance training, personnel in occupations with high physical demands should be stronger than personnel in occupations with low physical demands. This study compared the strength of incumbents in high and low physical demand U.S. Navy enlisted occupations to test this hypothesis.

Recent meta-analytic reviews provided the basis for a secondary hypothesis. Those reviews have shown that resistance training produces larger effects for untrained individuals than for trained individuals (Rhea, Alvar, & Burkett, 2002; Rhea, Alvar, Burkett, & Ball, 2003; Wolfe, LeMura, & Cole, 2004). If occupational tasks provide informal resistance training, the effects should be larger for sailors who are not engaged in training outside the workplace.

Method

Sample

Study participants were 147 volunteers serving aboard a U.S. Navy battleship.

Individual Characteristics

Study measures included individual difference variables that might affect strength. These variables included age, weight, percent body fat (PBF), FFM, and prior physical training experience. Weight was measured on a standard balance scale. PBF estimates were computed from circumference measurements using the Hodgdon and Beckett (1984a, 1984b) equation. FFM was estimated using the equation

$$\text{FFM} = [(1 - \text{PBF}) * \text{weight}] / 100.$$

Physical Training

Physical training experience was determined from self-reports. Subjects who reported no prior physical training ($n = 88$, 59.9%) were classified as untrained. The remaining participants, who reported between 1 month and 19 years of training ($Mdn = 24$ months), were classified as trained.

Occupation

Occupation was determined from self-reports of U.S. Navy Enlisted Classification (NEC). These reports gave either the rating name (e.g., Quartermaster, Personnelman) or number (e.g., 8300).

Occupational Physical Demands

Reynolds, Barnes, Harris, and Harris (1992) profiled the occupational demands of 63 entry-level U.S. Navy occupations. In their study, senior enlisted personnel used a 5-point rating scale to describe their occupation on a profile of 27 specific ability requirements. The profile included 4 physical demand ratings: strength, endurance, flexibility, and balance. Factor analysis indicated that these ratings could be combined into an overall physical demand (PD) rating. Vickers and Hervig (1998) showed that the PD rating was strongly positively related to hospitalization rates for injury and musculoskeletal disease. The PD rating was not related to rates for other diseases. Other occupational demand ratings (e.g., communication, reasoning) did not predict injury or musculoskeletal disease rates. This pattern of associations demonstrated convergent and discriminant validity for the physical demand ratings (American Psychological Association, 1985).

Physical demand ratings for the occupations of participants in this study provided a basis for dividing occupations into low- and high-demand groups. The rating distribution showed ratings between 1.69 and 1.90 and between 2.45 and 3.59. The gap from 1.90 to 2.45 was the only clear break in the distribution. To reflect this gap, NECs with ratings ≤ 1.90 were classified as less physically demanding occupations, and NECs with ratings ≥ 2.45 were classified as incumbents of highly physically demanding occupations. With this split, the sample included ~4 times as many sailors in high-demand occupations ($N = 117$) as in low-demand occupations ($N = 30$).¹

Strength Measures

Muscle strength tests were conducted on a Universal® Centurion multi-station system. The tests included biceps curl, shoulder press, latissimus pull down, bench press, and leg press. The starting weight for each test was based on the test subject's estimated FFM (see

¹Quartermaster (QM, $n = 2$), Operations Specialist (OS, $n = 18$), Electronics Warfare Technician (EW, $n = 1$), Personnelman (PN, $n = 6$), Intelligence Specialist (IS, $n = 1$), and Aerographer's Mate (AG, $n = 2$) were low-demand occupations. Signalman (SM, $n = 4$), Gunner's Mate (GM, $n = 22$), Storekeeper (SK, $n = 5$), Mess Management Specialist (MS, $n = 6$), Ship's Serviceman (SH, $n = 1$), Engineman (EN, $n = 7$), Machinery Repairman (MR, $n = 5$), Boiler Technician (BT, $n = 17$), Interior Communications Technician (IC, $n = 8$), Hull Technician (HT, $n = 7$), Hospital Corpsman (HM, $n = 2$), and Dental Technician (DT, $n = 2$) were high-demand occupations.

Individual Characteristics above). The resistance mass was increased in 4.5-kg (10-lb) increments until the person was unable to lift the weight stack.

The 5 strength test scores were combined into a general strength score.² Three factors were considered in adopting this strength index. First, muscle strength can be modeled as a general factor plus several specific factors (Vickers, 2003). The specific factors generally were defined by bilateral tests for specific muscle groups (e.g., left and right biceps curls). The present measures combined the bilateral muscle groups into a single measurement. The test results therefore provided a basis for measuring the general factor, but not the specific factors. Principal components analysis (PCA) confirmed the presence of a general strength component. The first component accounted for 67.0% of the total variance ($\lambda_1 = 3.35$). No other component approached Kaiser's (1960) extraction criterion ($\lambda < 0.66$ for each). All strength tests had substantial loadings on the first principal component (biceps curl, .854; shoulder press, .843; lat pull-down, .824; bench press, .890; leg press, .662). PCA scores were computed by the regression method.

Job performance models were the second reason for focusing on general strength. A latent trait representing general strength is strongly related to overall performance on a wide range of physically demanding U.S. Navy tasks (Vickers, 1995, 1996). Residual correlations that would indicate effects of specific muscle groups on specific tasks are small and unstable across samples. Generalizing these cross-sectional findings to changes in strength, changes in scores on specific strength tests are likely to be related to performance only through their association with changes in general strength.

Statistical considerations were the third reason for focusing on general strength. Five significance tests would be needed if each strength test had been considered individually. Performing multiple tests would increase the likelihood that at least one would be significant by chance. A more extreme significance criterion (e.g., $p < .01$) would protect against this risk (cf., Green, Thompson, & Poirer, 2001). However, the increased protection would be accompanied by a loss of statistical power. Important effects could be dismissed as chance findings. Focusing on the principal component variable as the overall index of strength differences when testing the primary study hypothesis made it possible to retain the $p < .05$ (one-tailed) criterion. Some results for the individual strength measures are reported below to illustrate that the PCA results represent a general trend.

²The Results section includes some significance tests for individual strength tests. These statistics are provided for descriptive purposes and are not used to draw inferences about the primary research hypothesis.

Analysis Procedures

Analyses were conducted with the personal computer version of the Statistical Package for the Social Sciences (SPSS, Inc., 1998a, 1998b). The general linear model procedure was used to perform analyses of variance (ANOVAs) and analyses of covariance (ANCOVAs). Preliminary tests analyses showed that the assumption of parallel regression lines was reasonable for each ANCOVA.

The statistical significance criterion for this study was $p < .05$ (one-tailed). Cohen's (1988) effect size (ES) criteria were applied to evaluate the practical and theoretical significance of observed differences. Effect size was:

$$ES = (\text{High} - \text{Low})/SD$$

where "High" and "Low" indicate average strength for the high- and low-demand occupational groups, respectively and "SD" is the pooled within-group standard deviation. The differences also were expressed as point biserial correlations (r_{pb}).

Results

Strength was greater in high-demand occupations (Table 1). This statement held for each individual strength test as well as for the PCA measure.

A 2-way ANOVA demonstrated the hypothesized interaction between occupation and physical training status (Table 2). Main effects were obtained for occupational demands, $F_{1,139} = 14.18$, $p < .001$, and training status, $F_{1,139} = 14.49$, $p < .001$. These main effects were qualified by the significant training status-occupational demands interaction, $F_{1,139} = 6.16$, $p < .006$. The effect of occupational demands was large ($ES = 1.32$, $r_{pb} = .51$) and statistically significant ($p < .001$) for untrained individuals. The effect of occupational demands was small ($ES = 0.38$, $r_{pb} = .13$) and statistically nonsignificant ($p > .160$) for trained individuals.

Table 1. Strength in Low- and High-Demand Occupations

	Physical Demand Level				<i>t</i> test ^a	Sig.
	Low		High			
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
General strength ^b	-.68	1.12	.17	.90	4.38	.001
Individual tests						
Bench press	138.50	31.55	154.35	21.42	2.60 ^c	.007
Biceps curl	66.33	14.97	77.74	13.90	3.94	.001
Shoulder press	100.86	22.68	115.09	19.03	3.46	.001
Lat pull-down	122.33	25.15	136.43	18.88	2.87 ^c	.004
Leg press	386.00	104.27	424.57	84.38	2.12 ^c	.035

^a *df* = 143, except *df* = 142 for general strength and shoulder press.

^b The method of computing general strength yields standardized scores (i.e., *M* = 0.00, *SD* = 1.00).

^c Based on separate variances estimates for the two groups based on significant ($.004 \leq p \leq .047$) heterogeneity of variance. Group variance was homogenous for all other strength measures.

Associations to Individual Attributes

Personnel were not randomly assigned to the occupational demand categories in this study. Thus, personal attributes might be confounded with group membership. Confounding would bias the study estimates of the effects of occupational demands. Bias would occur if the personal attribute that was confounded with occupational status also were related to strength (James, Mulaik, & Brett, 1982, pp. 71-80).

Two personal attributes could have contributed to biased estimates of the strength-occupation relationship. Older individuals were weaker ($r = -.26$, $p < .001$) and were more likely to be in low-demand occupations ($r_{pb} = -.41$, $p < .001$). Greater FFM was associated with greater strength ($r = .65$, $p < .001$) and with higher occupational demands ($r_{pb} = .22$, $p < .004$). PBF was not related to either strength ($r = -.03$, $p > .371$) or occupational demands ($r_{pb} = -.13$, $p > .056$), so this attribute could not bias the estimates of occupational effects.

None of the individual attributes could have biased the estimates of the effects of training history. Neither age ($r_{pb} = -.04$, $p > .305$) nor FFM ($r_{pb} = -.04$, $p < .314$) was significantly related to training history.

Table 2. Combined Job Demand/Physical Training Effects

	Low Demand		High Demand		ES	<i>t</i> test	Sig.
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Untrained	-1.27	1.01	.05	.86	1.32	5.38	.001
Trained	.05	.79	.33	.94	.38	1.00	.161

Note. Table entries are group means and standard deviations for the General Strength composite constructed in the principal components analysis.

ANCOVA controlling for age and FFM indicated that bias was only a concern among untrained individuals. Controlling for age and FFM reduced effect size by 50% for untrained individuals (Table 3). The same controls had no effect on the effect size among trained individuals.

Table 3. Effects Controlling for Age and FFM

	Untrained Partial			Trained Partial		
	ES	<i>r</i> _{pb}	Sig.	ES	<i>r</i> _{pb}	Sig.
None	1.33	.51	.001	.29	.13	.161
Age	1.35	.44	.001	.23	.11	.325
FFM	0.71	.36	.005	.31	.17	.100
Age+FFM	0.67	.28	.005	.23	.13	.166

Note. Effect size computed using raw standard deviation (*SD* = 1.00).

Discussion

The evidence was consistent with the hypothesis that performing occupational tasks increases strength. Personnel in physically demanding occupations were stronger than personnel in less-demanding occupations. The difference was larger for untrained individuals than for trained individuals. The difference among untrained individuals was smaller after controlling for FFM and age. However, even the reduced difference was statistically significant and large enough to meet Cohen's (1988) criteria for an effect that could be of theoretical and/or practical importance. This pattern of findings is consistent with the suggestion that physically demanding occupational tasks provide informal resistance training.

Informal resistance training would help explain known injury patterns. Physical training programs commonly produce rapid initial gains followed by slower growth as strength approaches an upper limit (Hodgdon, 1994). Thus, most of the effects of resistance training programs occur in the first 6 to 16 weeks of training (Wolfe et al., 2004). Injury rates are highest during the first few months of experience on the job during which time they drop toward a stable, long-term level (Helmkamp & Bone, 1987). The mirror image in these

trends would be expected if increasing strength were a factor in the falling injury rates.

The suggestion that occupational tasks provide informal resistance training may be surprising at first glance. Physically demanding occupational tasks typically are performed infrequently (Robertson & Trent, 1985). This fact makes it reasonable to wonder whether these tasks provide a suitable training stimulus. However, the tasks that comprise resistance training also are performed infrequently. Significant strength gains accrue in resistance training that consists of as little as 1 set of exercises performed 3 times per week (Rhea et al., 2002, 2003; Wolfe et al., 2004). If a typical exercise set consists of ~10 repetitions and takes <1 min to perform, 10 repetitions of a demanding occupational task every other day would provide a similar stimulus for increasing strength. Such tasks would take up a small percentage of the workday, so knowing that physically demanding tasks represent only a small percentage of work does not rule out training effects.

Several other lines of research provide additional reasons to believe that the occupational differences reported here could be the result of informal resistance training. First, programs using task simulations as training stimuli have produced strength gains (Genaidy, 1991). Second, the occupational difference was most pronounced in untrained individuals. This element of the findings is consistent with the pattern of resistance training effects identified in recent meta-analyses of formal resistance training programs (Rhea et al., 2002, 2003; Wolfe et al., 2004). Third, the present findings are not unique. Schibye, Hansen, Sogaard, and Christensen, (2001) reported similar relationships between occupational demands and strength ($.20 \leq r_{pb} \leq .67$, except for handgrip, $r_{pb} = .01$).

Occupational strength differences suggest two methods of reducing injuries. Strength standards for admission to physically demanding occupations are one option. This option is unattractive because it would reduce the number of people qualified for those occupations (Marston, Kubala, & Kraemer, 1981).

Formal resistance training is the second option for reducing injuries. This option could be a reasonable choice. Brief resistance training programs could suffice. For example, a program consisting of 1 set of maximal exertions 3 times per week for 6 weeks can produce substantial gains (Rhea et al., 2002, 2003; Wolfe et al., 2004). After this initial effort, maintenance training could consist of as little as 2 exercise sessions per week (Peterson, Rhea, & Alvar, 2004). If the relationship between strength and time lost as a result of accidental injuries were known, a cost-benefit analysis of this option would be possible. The time investment for training could be estimated

from recent meta-analyses. These investments could be weighed against reductions in time lost to injury.³

Possible study limitations must be kept in mind when evaluating the results. Study participants served aboard a U.S. Navy battleship during the 1980s. Ships in this class have been decommissioned at this time. Some specific tasks performed in physically demanding occupations aboard battleships may have been unique to this class of ships. If so, the results might not generalize to the types of ships found in today's U.S. Navy. However, the rationale for on-the-job resistance training depends on the level of exertion, not the specific tasks performed. The basic hypothesis would be expected to generalize to any work that involves intermittent moderate to heavy physical exertion.

The proposed explanation does not apply to all injuries. The explanation is most relevant to on-duty injuries. These injuries may comprise as little as 25% of injury-related hospitalizations among U.S. Navy personnel (Ferguson, McNally, & Booth, 1985). However, effects of resistance training might not be limited to this subset of the total injury burden. One reason is that the actual proportion of on-duty accidents may be higher than 25%. Duty status is listed as "unknown" for many hospitalizations (Amoroso, Smith, & Bell, 2000). Also, increased strength might reduce the risk of some off-duty injuries (e.g., sports injuries).

The evidence presented here is consistent with the hypothesis that physically demanding U.S. Navy occupations provide informal resistance training. The inference that occupational tasks provide informal resistance training is plausible when the present results are considered in the context of experimental studies of resistance training. The associated increase in muscle strength provides plausible explanation for the relationship between experience and lower injury rates. Brief preparatory resistance training programs (e.g., 2 sessions per week for 6 weeks) therefore might be a means of reducing the high injury rates seen among inexperienced personnel in physically demanding U.S. Navy occupations. Such programs could be one means of achieving injury rate reduction goals.

³Resistance training also could improve job performance (Vickers, 1995, 1996). However, improved performance would accrue only if the person continued to work at or near his or her maximum capacity. This increase would match performance to the individual's strength limits. The matching would have an associated risk of overexertion (Bernard, 1997) and injury (Chaffin et al., 1978). The complexities of designing a program to deal with a performance-injury trade-off would be substantially greater than the problems associated with designing a simple injury reduction program.

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1. Report Date (DD MM YY) 1 Sep 2004	2. Report Type Interim	3. DATES COVERED (from - to) Sep 2003 – Jan 2005
4. TITLE AND SUBTITLE Occupational Differences in Muscle Strength of U.S. Navy Enlisted Personnel		5a. Contract Number: 5b. Grant Number: 5c. Program Element: 5d. Project Number: 5e. Task Number: 5f. Work Unit Number: 60109
6. AUTHORS Ross R. Vickers, Jr., James A. Hodgdon, Edward J. Marciniak		9. PERFORMING ORGANIZATION REPORT NUMBER Report No. 05-10 10. Sponsor/Monitor's Acronyms(s) 11. Sponsor/Monitor's Report Number(s)
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Health Research Center P.O. Box 85122 San Diego, CA 92186-5122		
8. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES) Chief, Bureau of Medicine and Surgery Code M53 2300 E St NW Washington DC 20372-5300		

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13. SUPPLEMENTARY NOTES

14. ABSTRACT (maximum 200 words)
Injury rates are high in physically demanding U.S. Navy enlisted occupations. Injuries are particularly common among inexperienced personnel in those occupations. Overexertion is one likely cause of the excess injuries. Over time, repeated performance of physically demanding tasks may reduce injury risk by increasing strength of the personnel in physically demanding occupations. The strength of personnel in high and low physical demand occupations was compared to test this possibility. Ratings by senior enlisted personnel were used to define high- and low-demand occupations. Biceps curl, lat pull-down, shoulder press, bench press, and leg press tests performed on a Universal® gym measured strength. As predicted, sailors in physically demanding occupations were stronger ($p < .001$ for the first principal component of the strength measures). For personnel who reported that they did not engage in regular physical training, the occupational difference was comparable to effects seen in formal resistance training programs. The difference was much smaller for personnel who reported that they did train regularly. The inference that occupational tasks provide informal resistance training is plausible when the present results are considered in the context of experimental studies of resistance training and task surveys describing the frequency and intensity of physical task demands in U.S. Navy jobs. Brief formal resistance training prior to entering the job may be a means of reducing the exceptionally high injury rates among inexperienced personnel.

15. SUBJECT TERMS
physical fitness, muscle strength, occupation, resistance training

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UNCL	18. NUMBER OF PAGES 14	19a. NAME OF RESPONSIBLE PERSON Commanding Officer
REPORT UNCL	b.ABSTRACT UNCL	c. THIS PAGE UNCL			19b. TELEPHONE NUMBER (INCLUDING AREA CODE) COMM/DSN: (619) 553-8429