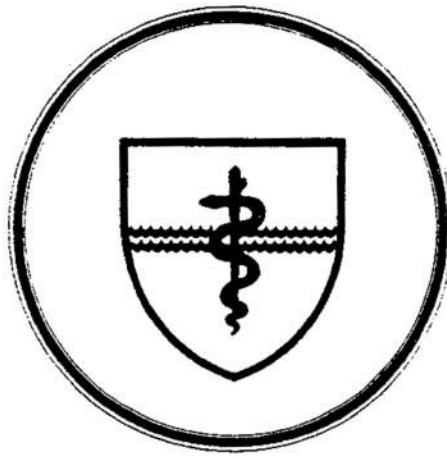


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**NAVAL SUBMARINE MEDICAL
RESEARCH LABORATORY
SUBMARINE BASE, GROTON, CONN.**



REPORT NUMBER 962

THE RELATIONSHIP OF JOB PERFORMANCE TO PHYSICAL FITNESS
and
ITS APPLICATION TO U. S. NAVY SUBMARINERS

by

Brad L. Bennett, LT MSC USN and Kenneth R. Bondi, CDR MSC USN

Naval Medical Research and Development Command
Research Work Unit MF58. 524. 006-2104

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SUMMARY PAGE

PROBLEM

The present submarine environment induces no acute medical problems that hinder job performance of a typical submariner. However, a large percentage of a submarine crew is physically inactive during patrol and this may compromise the potential operational efficiency of a patrol mission. Additionally, these crews are engaging in a lifestyle that is known to be an apparent risk for the development of coronary artery disease. These risk factors include smoking, high caloric intake, and high coffee consumption. The question of whether this lifestyle during patrol accelerates the development of coronary heart disease has not been resolved.

FINDINGS

Physical inactivity during patrol is a direct result of limited space to adequately exercise, resulting in elevated resting heart rates and prolonged heart rate recovery from exercise as compared to pre-patrol data. Furthermore, a decline in maximal oxygen consumption ($\dot{V}O_2$ max) has been recently demonstrated and there may be a concomitant decrease in brain tissue oxygenation resulting in an impairment of daily job performance during a patrol. Finally, the majority of the literature reviewed consistently supports the findings that those individuals who are physically fit perform significantly better cognitively and reveal less symptoms of stress.

APPLICATIONS

It is our belief that an implementation of an aerobic exercise regime would help maintain and in some cases improve physical fitness and lessen the stresses that are associated with the submarine mission. The physical and psychological benefits of an exercise program would augment daily job performance. Increased performance is especially necessary during emergency conditions, a time when cardiovascular and cognitive functions need to be at peak condition.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Naval Medical Research and Development Command work unit - F58524 MF58524006-2104 "Cardiorespiratory fitness before and after long patrols." The present report is No. 2 on the work unit. The manuscript was submitted for review on 3 September 1981, approved on 29 September 1981, and designated as Naval Submarine Medical Research Laboratory Report No. 962.

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ABSTRACT

During a nuclear submarine patrol (SSN/SSBN) physical activity is severely curtailed for a majority of individuals because of the closed confines of the submarine. Work schedules and studying for self-advancement may also contribute to an inhibition of exercise even in submariners normally motivated to exercise. Two resultant effects of physical deconditioning are a rapid decrement in one's maximal oxygen consumption ($\dot{V}O_2$ max) and an increasing development of anxiety and depression. Furthermore, submariners are known to have a high caloric intake, high coffee ingestion, and a high rate of smoking. It is well known that these factors all contribute to the development of coronary artery disease (CAD). The question of whether career submariners are predisposed to a premature development of CAD has not been resolved. Implementation of a shipboard exercise program will prevent physical deconditioning and will maintain a sense of well-being during patrol and ultimately may lead to increased effectiveness and efficiency of the submarine crew.

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THE RELATIONSHIP OF JOB PERFORMANCE TO PHYSICAL FITNESS AND
ITS APPLICATION TO U. S. NAVY SUBMARINERS

1.0 INTRODUCTION

Submarine medicine is "essentially the study and solution of the problems associated with continuous incarceration of large groups of men, without access to their normal earthly environment, in a totally closed, highly mobile, underwater weapon-carrying platform of high technical sophistication" (Rawlins, 1979). While great advancements have been made in submarine medicine and physiology by the efforts of both American and foreign investigators, there still is a need for further clarification of the human problems associated with prolonged submergence to 1) assure the future health and safety of submariners and 2) optimize their performance.

Currently it is a primary mission of the Naval Submarine Medical Research Laboratory (NSMRL) to carry out research and development efforts to augment operational efficiency through the enhancement of physiological and psychological well-being of submarine personnel. This paper will attempt to demonstrate the importance of physical fitness and its relationship to psychological function and cognitive performance of submariners. In this attempt we will first define physical fitness, how it is attained, and what occurs physiologically as a result of exercise. Second, we will review the literature concerned with the relationship of sedentary life style and coronary artery disease (CAD) and show how physical activity can attenuate cardiovascular risk factors. Third, we will describe the relationship of job perform-

ance and good physical fitness and how they interact to increase the level of job efficiency by enhancing mood states and by decreasing the deleterious effects of fatigue. Fourth, and finally, we will attempt to relate physical fitness and job performance variables to crew efficiency during extended submarine patrols.

2.0 PHYSICAL FITNESS

2.1 Definition

The definition of physical fitness can be varied to fit the needs of a specific situation. For example, a well-known physiologist defines physical fitness to be, "the amount of maximal oxygen uptake ($\dot{V}O_2 \text{ max}$)" (Astrand, 1977). Lamb (1978) defines physical fitness as "the ability to meet the needs of the present and potential physical challenges of life with success." Our interpretation of the latter is that individuals should have an appropriate balance of cardiovascular endurance, muscular strength, muscle endurance, flexibility, and coordination as well as neuromuscular control to meet the daily requirements of life and to effectively respond to emergency situations. Shephard (1978) views physical fitness as "an exercise in ecology - the matching of the individual to his environment: physical, social, and psychological." It is this holistic approach, we believe, that offers the best way to integrate the topic of physical fitness and performance. This will be made evident in the following pages.

2.2 Attainment of cardiovascular physical fitness.

The attainment of cardiovascular fitness can be derived from many forms of physical activity. The American College of Sport Medicine (ACSM) (1978) gives the following guidelines for the quality and quantity of exercise needed for the maintenance of physical fitness in healthy adults:

- (1) Frequency of exercise: 3-5 days per week.
- (2) Intensity of exercise: 60-90% of maximal heart rate reserve or 50% to 85% of maximum oxygen uptake ($\dot{V}O_2$ max).
- (3) Duration of exercise: 15 to 60 minutes per session of continuous aerobic activity. Duration is dependent on the intensity of activity, the lower the intensity the longer the duration.
- (4) Mode of activity: Any activity that uses the large muscle groups and that is aerobic in nature, e.g., jogging, walking, hiking, swimming, skating, bicycling, running, cross-country skiing, and rope skipping.

Depending upon the initial level of cardiovascular fitness and the quality of exercise, increases attainable in $\dot{V}O_2$ max range from 5 to 25% or even greater (ACSM, 1978). The improvement in $\dot{V}O_2$ max begins to level off when the exercise period is increased above 3 days per week, but the current literature indicates that there are added improvements when physical fitness programs are conducted 5 or more days per week. Exercising

less than two days per week does not show a significant improvement in $\dot{V}O_2$ max (Pollock, 1973). It is apparent that frequency, intensity, and duration of exercise are all important for eliciting cardiovascular improvement. Exercising fewer than 2 times per week, less than 50% $\dot{V}O_2$ max, and less than 10 minutes per day is inadequate for developing and maintaining aerobic fitness.

2.3 Physiological Response to Exercise.

At the start of exercise, changes take place in the physical and chemical environment of the body: body temperature rises, blood pH decreases, oxygen in the tissues decreases and carbon dioxide increases. The body's control mechanism senses these changes through various chemical and physical receptors. In response, the neural and hormonal pathways stimulate target organs (e.g., heart and lungs) and a functional response occurs. These feedback mechanisms allow one to maintain homeostasis during exercise.

A physiological adaptation begins when exercise is conducted on a routine basis. Exercising muscles increase their capacity for contraction and energy production. There are increases in the number of muscle enzymes, a speeding up of chemical reactions and a reduction in the energy substrate needed per given work load. In general, there is greater capacity to deliver and utilize oxygen and energy substrate at a higher physical work capacity for a greater duration of time.

2.4 Effects of Physical Inactivity

Numerous studies have documented that significant physiological changes occur between two and twelve weeks when regular exercise stops (Lamb, 1978; Fried and Shephard, 1969; Stremel, et al, 1976; Pate, et al, 1978). Saltin, et al (1968) demonstrated that bed rest for three weeks in young adults had severe effects on the working capacity of the circulating system. They reported decreases of 28% in $\dot{V}O_2$ max, 11% in heart volume, and 26% in cardiac output. Heart rate at an oxygen uptake of 2 liters/minute increased from 145 to 180 bpm.

In a study by Stremel, et al (1976), seven men were confined to bed for 14 days. One group of subjects did no exercise, one performed two 30-minute periods of static exercise, and a third performed two 30-minute periods of supine bicycle ergometry at 68% $\dot{V}O_2$ max. The results indicated that $\dot{V}O_2$ max, as compared with pre-bed rest values, decreased 12.3% with no exercise, 9.2% with dynamic exercise and only 4.8% with static exercise. It was noted in this study both the capillary-to-tissue transport of oxygen was impaired and a decrease of oxidative enzymes in the mitochondria was observed. Apparently $\dot{V}O_2$ max was limited because of O_2 utilization by the exercise muscle rather than centrally, since submaximal and maximal heart rates were similar in all three conditions following bed rest. It was concluded that during bed rest, neither static nor dynamic exercise prevented decrements in oxygen consumption. Long-term

inactivity causes men to lose 11-14 ml O_2 /kg min of aerobic power between the ages of 25 to 55, a loss of about 25% in 3 decades (Shephard, 1978). Astrand (1973) and Bailey, et al (1974) reported losses of 31% and 39% over a period of 4 decades. Asmussen and Mathiasen (1962) reported a loss of 0.57 ml O_2 /kg min per year after 25 years of age in physical education students.

3.0 LONG-TERM HEALTH OUTLOOK

3.1 Sedentary Life style: The Effects on Physical Work Capacity

Sedentary life style and the monotony of the daily work routine can result in fatigue, affecting psychological and physiological well-being. It has been implied that the adaptive process to urbanization has resulted in an increased development of coronary artery disease (Morris and Raffle, 1954; Kannel, 1967; Paffenbarger, et al, 1970). This disease kills more Americans each year than any other disease (Rosenberg and Klebba, 1979). The hypothesis of "multiple risk factors", arrived at through the years of epidemiological research, forms the developmental theory of coronary artery disease. The risk factor theory, although indicating direct association to CAD, must be scrutinized, since these associations do not necessarily indicate causality.

Identification and modification of the primary risk factors has helped greatly towards decreasing the incidence of CAD. The American Heart Association has listed the following as either primary or secondary risk factors: age, sex, family history of CAD, cholesterol, triglycerides, hyper-

tension, cigarette smoking, impaired vital capacity, obesity, glucose intolerance, diabetes, hyperuricemia, hypothyroidism, socio-psychological stress, and physical activity. Of these, cigarette smoking, cholesterol, and hypertension are consistently related statistically to the incidence of CAD.

3.2 Physical Activity and CAD Risk Factors

In assessing the potential effects of physical activity in the prevention of CAD, there are two additional areas of research which provide significant evidence for its role in decreasing mortality and morbidity. These are (1) the relationship of physical activity to the attenuation of CAD risk factors, and (2) the relationship of physical activity to the reduced incidence of CAD shown by epidemiological studies.

Cooper, et al, (1976) studied 3,000 men (average age = 44.6 years) for CAD risk factors. A consistent inverse relationship was observed among physical fitness categories, resting heart rate, body weight, percent body fat, cholesterol, triglycerides, glucose, and blood pressure.

Attempts have been made to compare specific life style patterns and the incidence of CAD. These surveys have contrasted men who have been physically active and inactive at work. Comparisons have been made between conductors vs drivers of double-decker buses (Morris, et al, 1966); mail carriers vs clerks in postal services (Morris and Raffle, 1954); farmers vs pro-

fessional men (Zukul, et al, 1959); San Francisco longshoremen whose jobs were classified as either physically active or physically inactive (Paffenbarger, 1977); and others. The results of these studies show conclusively that there is a strong inverse relationship between the quality of physical activity in which one is engaged and the incidence of CAD. These studies consistently support the concept that a life style which incorporates a moderate level of physical activity for maintaining a sound cardiovascular system is needed. Strenuous physical activity does not appear to reduce further the incidence of CAD.

4.0 PHYSICAL FITNESS AND PERFORMANCE

4.1 Psychological benefits

The psychological benefits of physical fitness have been researched by many investigators. They have studied mood profiles of fit and unfit runners (Wilson, et al, 1980; Folkins, 1976); the effects of exercise on anxiety and depression (Lion, 1978; Blue, 1979; Folkins, et al, 1972; Higdon, 1978); exercise and personality traits (Merzbacher, 1979; Young and Ismail, 1974b); and the effects of exercise on perception of self and others (Jorgensen and Jorgensen, 1979). In general, these studies indicate that those who routinely exercise report that they feel less depressed, have less anxiety, and are more confident. However, these studies show that the most significant psychological changes affected by an exercise program, appear in those participants who are very unfit and who have at least a moderate degree of anxiety. The initial research in the area of physical fitness and psychological well-being was done

by Cureton (1963). Data were collected over a 10-year span from 2,500 adults who were followed throughout a physical conditioning program. The results indicated that nervous tension disappears with physical exercise. A recent study (Wilson, et al, 1980) tried to determine whether a given amount of exercise was related to a certain degree of improved mood state. This study consisted of 3 groups: 10 marathoners, 10 joggers, and 10 non-exercisers. The results showed marathoners had significantly less depression, less anger, less confusion, and more vigor than the joggers and non-exercisers. The joggers reported significantly better mood states than non-exercisers. This study, although it uses a cross-sectional approach, suggests that regular exercise and the amount of activity are important for improving positive mental health.

The effects of employee fitness programs on productivity and health have also been investigated (Shephard, et al, 1980; Shephard and Cox, 1980; Everett, 1979; Howard and Mikolackki, 1979; and Heinzelman and Bagley, 1970). These studies have shown that workers engaged in regular physical activity miss fewer days because of sickness than non-exercisers. Linden (1969) reported an inverse relationship between maximal oxygen consumption and the number of absences.

Psychological stress plays a key role in many illnesses (Lazarus, 1974). Stress and disease appear to be related, since organ systems function poorly during periods of stress. Therefore, stress has been viewed as a contributor to the incidence

of CAD. It has been assumed by physical fitness educators that physical fitness is associated with emotional health (Kane, 1972). Harris (1973) suggests that physical activity may produce a positive psychological response in much the same way as the altering of a negative psychic state can improve a particular somatic condition.

Data collected at Cooper's Aerobic Clinic cited numerous cases where exercise controlled or eliminated emotional responses to stress (Cooper, 1968). DeVries (1968) reported a 58% reduction in muscle tension after acute exercise and a 25% decrease (experimental) and 24% increase (control) in muscle tension from chronic exercise. However, 6 of 11 subjects in the exercise group were very tense at the beginning of the physical training period. This suggests, as stated above, that exercise may in fact provide a greater therapeutic aid for those individuals who are highly stressed than for those who are "normal".

Layman (1974) reviewed studies dealing with acute and chronic effects of physical activity on perception, body image, self concept, aggression and anxiety. She concluded that physical activity in "normals" has not been shown to influence skill, perceptual ability and auditory perception. She admitted, however, that this may be a function of experimental design and an inappropriate use of statistical analysis.

Both positive and negative effects of physical activity and/or fitness on self-concept have been reported. Changes in self-concept are likely to occur as a result of physical education programs. The relationship between anxiety and

physical activity has been studied by numerous investigators (Layman, 1974; Karbe, 1966; Hanson, 1970; Popejoy, 1967). Karbe (1966) reported that anxiety scores for 92 female college students were reduced after a 16-week swimming class. Popejoy (1967) also reported reduction of anxiety scores for 22 sedentary women after 20 weeks of physical fitness. Young and Ismail (1974b) studied the effects of a four-month physical fitness program on personality characteristics in high and low fitness adults. The post-test evaluation revealed that regardless of age, the high-fit group was more intellectually inclined, emotionally stable, composed, self-confident, easy-going, relaxed and less ambitious than the low-fit group. The authors also reported the personality differences between fitness groups were distinct, the ability of exercise to induce changes during the four months is less clear even though all groups increased on the personality dimensions between test periods.

Young and Ismail (1974a) reported on a before and after four-year study of 48 regular and non-regular adult exercisers who were tested for selected personality traits. The exercising group was found to be more self-confident and to possess greater emotional stability, while conversely, the convert exercisers were found to be more conservative of temperaments. It was noted that the regularly active groups scored significantly lower anxiety scores than the other groups at both test periods indicating greater emotional stability. These findings also indicate that the relation-

ship between physical condition and emotional stability tend to be stable with time. In contrast, the group that displayed more conservative of temperament than the active group from the pre-test failed to exhibit this difference four years later. These workers stated that the greater level of emotional stability exhibited by the regular active groups may reflect the results of a life-long exercise program on the general body chemistry.

Blumental, et al (1981) have recently examined the psychological effects of a 10-week aerobic exercise program. Sixteen male and female subjects participated in this study, in addition to sixteen matched control subjects. Psychological testing was conducted on both groups one week before and one week after the exercise program. It was noted that the exercise program changed in a desirable direction in every analysis (e.g., less tension, less depression, less fatigue, and more vigor) after the exercise program.

In the final preparation of this position paper, a review article on physical fitness training and mental health was published (Folkins, 1981). In this extensive review, Folkins argues that poorly designed studies have been reported on physical fitness and its relationship to psychological health. Apparently the majority of the "true" experiments were performed with children, and where pretest-post test designs were employed, only one group was used with no controls. It was stated the most often used design by researchers was with a non-equivalent control group. Other complaints of these studies are selection bias when

using highly motivated subjects only in the experimental group but not in the control group. Beyond the technical and theoretical problems associated with these studies, these data suggest, however, that increased physical fitness leads to improved mood, self-concept, and work behavior. Folkins notes the evidence so far is less clear whether the effect on cognitive function are evident, although cognitive performance is sustained during and after physical stress. He concludes "Theoretical speculation suggest that fitness training should help people cope with physical and psychological stress."

4.2 Motor and Mental Performance During and After Exercise.

Are motor tasks and cognitive function improved during and immediately after various levels of exercise? Physical exercise can be described as a stimulus, similar in effect to the mental arousal caused by threat or excitement. The effects of such stimuli on the human body are similar and include increases in muscle tension, respiration, heart rate, and level of circulating hormones. The relationship between stimulation and performance takes the form of a parabola (specifically known as the inverted U) as defined by Duffy (1962). This means that the level of performance increases to a threshold and then deteriorates with increasing stimulation. Specific performance tasks may have corresponding optimal level of activation. Gutin, et al (1971) studied the effects of exercise on arm steadiness at heart rates of 100, 130, and 160 beats per minute (bpm). Steadiness was worse following exercise,

although its deterioration was the largest after 100 bpm. On recovery, steadiness performance improved paralleling recovery heart rates. This study indicates that exercise is harmful to a task where there is a large demand for central inhibition. The opposite occurs for tasks requiring speed of movement. Two studies by Levitt (1971, 1972) reported reaction time (releasing one button and depressing another 5 inches away) decreased linearly as heart rates were increased from 115 to 175 bpm. Other studies using tasks towards the middle of the inhibiting continuum have not resulted in consistent findings. Complex tracking and bouncing a ball into a target were worse following exercise, while juggling and problem solving were better. Tasks such as stylus maze, pursuit rotor, and simple reaction time were unchanged following strenuous exercise (Gutin, 1973).

A number of studies have reported on the response of intelligence tasks during and after exercise. Performance on a digit symbol substitution task was improved following mild exercise, but was worse following an exhaustive treadmill run (Gutin, 1973), substantiating the inverted U theory (Duffy, 1962). In these studies there appears to be a critical difference in performance depending on whether the task was done during or following exercise.

4.3 Physical Fitness and Mental Performance.

Gutin (1966) tested the hypothesis that physical fitness affects the ability to perform mental tasks following physical and mental stress. His results showed only a moderate relationship between

between the level of fitness and the quality of the mental tasks performed. He argued that the stress may have been too mild and the fitness level between the experimental and control group might have been too similar to test his original hypothesis accurately. Sjoberg (1980), again studying two different fitness groups during and after exercise, reported that recovery heart rates and mental performance were significantly better in the fit group than in the unfit group. A review article by Weingarten (1973) described numerous works comparing fit with unfit subjects. The data consistently show that when complex cognitive problems were to be solved during stress, the fit individual outperformed the non-fit. However, when problems were less complex and the stress levels were not far apart, the quality of mental performance was usually the same in fit and unfit subjects.

4.4 Fatigue and Performance.

Bills (1937) has classified fatigue as either subjective (related to an experience awareness or feeling) or objective (related to the change in the body process during a performance task). Whether the fatigue mechanism is physiological or psychological in nature, or a combination of both, the end result is a reduction in work efficiency and productivity. Physiological fatigue has been discussed in detail by Admudsen, 1979 and Simmonson and Weiser, 1976. Characteristically, muscle fatigue can be explained by an accumulation of metabolic end products within the muscle fibers. When blood lactic acid concentrations reach approximately 400 mg/100 ml and the pH is 7.0, energy substrate

release is inhibited, resulting in physiological fatigue (Shephard, 1974). Other possible factors involved in physiological fatigue are (1) blockage in the transmission of impulses at the neuromuscular junction, and (2) a possible failure of excitation-contraction coupling (Shephard, 1974).

Psychological fatigue can be differentiated from physiological fatigue in that mental fatigue necessitates a change of environment rather than a rest from physical work. Bartley and Chute (1947) and Simmonson and Weiser (1976) classify the forms of mental fatigue as follows: boredom (dissatisfaction with work); tedium (frequent interruptions); monotony (estimation of one's surroundings); and common symptoms like tiredness and weariness.

In essence, fatigue has a multi-dimensional relationship, being associated with human physiology, biochemistry, psychology, and the physical environment. Fatigue can be attenuated by increasing physical fitness, resulting in changes of efficiency and utilization of O₂, muscle strength, posture, thermoregulation, perception of pain, mood, arousal, self-esteem and environmental surroundings (Shephard, 1974).

4.5 Work Rest Cycles, Sleep Patterns, and Performance.

One obvious cause of fatigue is acute or chronic sleep loss. It has been well documented that a decrement of sleep will lead to impaired performance (Williams, Lubin, and Goodnow, 1959; Adams and Chiles, 1960; Donnel, 1969; Alluisi, Chiles, and Smith, 1964). Another

factor that influences the effects of sleep loss on performance is the work-rest schedule. Alluisi, Chiles, and Smith (1964) found that work-rest schedules different from the usual 8 hours on 16 hours off (8:16) causes the efficiency and the reliability of tasks performed to decline. Researchers have also described psychophysiological changes after prolonged deprivation of sleep (Naitoh, et al, 1971); EEG and circadian rhythm cycles during nap sleeping (Moses, et al, 1978; and the effects of work-rest cycles and biochemical changes during shift work on performance (Moses, et al, 1978; Hall, et al, 1979; Ruthenfranz, et al, 1977). In 1965, Hartman and Langdon reported on the effects of performance (psychomotor task) after sudden awakening. The results showed significant decrements upon awakening as compared to pre-sleep values. The decrement of performance was approximately 25% and a systematic minute-by-minute recovery was observed. At the tenth minute, however, subjects still were not performing at pre-sleep levels. It was suggested that 25-30 minutes would be needed to reach pre-sleep levels. Sleep researchers suggest that poor performance due to sleep loss could be avoided through identification and selection of personnel who are resistant to, and can function on, reduced sleep.

4.6 Exercise, Sleep and Performance.

Several recent theories concerning the role of slow-wave sleep (SWS) on bodily function have stressed the importance of its physiologically restorative function (Oswald, 1974; Hartman, 1973). Zloty, et al (1973) observed that long distance runners had more SWS than a group of college students. Baekeland and Lasky (1966) found

increases in SWS subsequent to daytime exercise in subjects who participated in regular activity. Shapiro, et al (1975) reported increases in SWS following graded exercise in trained subjects. However, Harris (1968), Zir, et al (1971), as well as Browman and Tepus (1976) found non-significant changes in SWS in normal subjects following various amounts of exercise. It is well known that SWS increases on nights following sleep loss (Moses, et al, 1975). Changes in the SWS sleep patterns are likely a combined effect of sleep loss and exercise.

Shapiro, et al (1975) studied SWS patterns in two highly trained males after 6 days of repeated graded exercise. The subjects cycled at 50% $\dot{V}O_2$ max for 2, 4, 6, hours, respectively. On the fourth night the subjects exercised for 80 minutes at 78% $\dot{V}O_2$ max. The results showed a progressive increase in SWS. The study supports the hypothesis that SWS patterns have specific restorative function after physiological fatigue.

Griffin and Trinder (1978) hypothesized that the discrepancy in the literature on the SWS following daytime exercise exists because fitness was not taken into account. Their results support the SWS hypothesis by showing that the fit group had higher initial SWS, and that following exercise, the level of SWS increased in the fit and remained unchanged in the unfit subjects. It is a generally supported concept that physically fit individuals have more periods of SWS (Baekeland and Lasky, 1966). Griffin and Trinder (1978) reported disrupted sleep patterns in unfit subjects following a 4-mile run. In contrast, the fit group slept more soundly. Shapiro and Verschoor (1981) reported that their subjects' SWS was high after a normal marathon training run, and

also after the night immediately following the marathon.

Runners are known to fall asleep faster and experience less disruption of sleep during the night. Essentially, this means a fit individual needs less sleep than his or her sedentary counterpart. Baekeland and Lasky (1966) studied the effects of exercise deprivation on sleep patterns and other psychological reactions. Fourteen adults were studied over a 30-day period and followed a schedule of two nights of exercise followed by 4 nights of no exercise. SWS was greater on the second night of exercise as compared to the third night of no exercise. The psychological stresses reported were wakefulness and an increase in REM sleep during the deprivation period. It was stated that these changes were associated with anxiety or increased arousal. Subjective feedback from the subjects indicated that their sleep was impaired. The authors content that physical activity allows a greater benefit from sleep and that this effect may help explain the frequent reports by those who habitually exercise that they feel better and are more alert during the day.

Lubin, et al (1976) studied the effects of exercise on performance after sleep loss. It was thought that exercise would provide a temporary arousal stimulus during sleep loss, although continued exercise would cause deterioration in mood and performance. The subjects were assigned to either a nap group, a bedrest group, or an exercise group. Measures of addition, auditory vigilance, mood, and oral temperature were obtained during 40 consecutive hours. The results showed that the exercise group had the greatest decrement in all the

measures, followed by bed rest and the nap group. It was concluded that exercise exacerbates performance decrement after a sleep loss period.

5.0 SUMMARY.

Physical fitness can be achieved by numerous kinds of physical activity. Aerobic type activities, however, provide the greatest level of cardiovascular fitness. With properly executed activity as defined by adequate intensity, duration and frequency, a physiological adaptation begins. Notably, the delivery and utilization of oxygen at the cellular level is enhanced during submaximal and maximal exercise, allowing the human body to function more efficiently both during rest and exercise.

Psychological improvements resulting from regular physical activity, are manifested by a decrease in the level of anxiety, depression, and hostility. These psychological changes may be the result of an increased availability of oxygen and glucose through enhanced cerebral circulation and other physiological and biochemical adaptations. The greatest improvements of physical and mental function are shown in subjects who are initially sedentary and reveal signs of anxiety and depression.

Physically-fit individuals subjectively state that they have more vigor throughout the day and objectively display less mental and physical fatigue. They also show favorable slow wave sleep patterns and an increased quality of sleep and, therefore, may be more tolerant to sleep loss than their sedentary counterparts.

A routine physical fitness program would substantially improve one's long-term health outlook by decreasing

cardiovascular risk factors. Additionally, the increased efficiency and enhancement of mental state will be reflected in improved daily function. Furthermore, physical fitness adaptations may include a feedback mechanism and/or a direct effect on the brain leading to an enhancement in the sense of well-being, and may, in fact, be associated with a decrease in stress related disease.

6.0 APPLICATIONS TO THE SUBMARINE ENVIRONMENT.

6.1 Physical Fitness Aboard Submarines

Physical fitness in the military has been encouraged and should continue to be promulgated as a major component of military life style. In July 1980, the Navy adopted Cooper's (1978) "Aerobic" fitness program. Ideally, each military command should implement this aerobic program and oversee that every man and woman develops a regular aerobic program with progression and moderation. It is, however, difficult to carry out the majority of outlined aerobic activities on a submarine because of physical limitations. Work schedules and limited physical space for activity forces most submariners into an inactive life style that includes reading, card playing, movies, and a tendency to over-eat.

Gillingham (1965) tested the use of a bicycle ergometer as the mode for physical exercise aboard submarines. Twenty-five subjects cycled every day for 15 minutes and 25 subjects acted as controls. All subjects received a Harvard step-test at the beginning and at the end of the patrol. The exercise group exhibited a 36 bpm drop in

post-step test recovery heart rates after the patrol. The control group showed no change in recovery heart rates.

Farrier (1965) studied physical fitness before and after patrol also, using exercise recovery pulse rates as the basis (Schneider Index) for physical fitness. His results showed a lower than expected fitness score for a group that exercised occasionally or not at all and an increased score for those who exercised daily. Exercise tolerance in 132 British submariners was studied by Edmondstone (1978) before and after a 6-week patrol. This study also showed a deterioration of physical fitness as indicated by a decrease in exercise tolerance by using a resting and recovery heart rate formula.

The physiological adaptation to inactivity during a submarine patrol has a direct association with decreased physical work capacity. Bondi, et al, (1980) first showed that physical activity, as measured by pedometry, was reduced by approximately 50% aboard a Fleet Ballistic (FBM) submarine during a 67-day patrol as compared to a control period ashore. $\dot{V}O_2$ max was then measured in 17 crew members before and after the patrol and was found to decrease 13% (38.8 mL/Kg min vs 33.7 mL/Kg min).

In summary, physical deconditioning can be directly attributed to inactivity during submarine patrols. Common characteristics following patrols in the studies listed above are elevated resting heart rates and prolonged heart rate recovery as compared to pre-patrol data. In addition, a decline in maximal oxygen consumption ($\dot{V}O_2$) following patrol has been demonstrated. Both physical fitness indicators (H.R. and $\dot{V}O_2$) consistently support the deterioration of physical fitness during submarine patrols.

6.2 Disease and Coronary Artery Disease Risk Factors in Submariners.

Recent studies of active Navy personnel have shown that biochemical alterations are related to the amount of time spent on active submarine duty (Tappan, et al, 1975; 1979). These biochemical changes show trends towards increased serum cholesterol, uric acid concentration and an increased rate of utilization of glucose after a tolerance test (Shivertaker, 1974; Campbell and Rahe, 1974). These trends are correlated with the years of submarine service and age. As noted earlier, serum cholesterol is a primary factor associated with the development of cardiovascular disease. Additionally, an increased insulin production to a carbohydrate load may be a precursor to the development of diabetes mellitus (Hoffman, 1964).

Tappan, et al (1979) reported biochemical and hematologic data collected from 1,017 active duty submariners. The results revealed that percent body fat as determined by skinfold thickness procedure was higher than groups of men of similar age, although total body fat was within the range of high normality. It was noted serum cholesterol levels, cigarette smoking, relative weight, and blood pressure appear to be the factors directly responsible to the cardiovascular disease risk. Tappan (1979) states these submariners are not at an increased risk for CAD as compared to other American men. Tappan (1979) does point out there was a significant tendency for the total risk of CAD to increase with length of service as well as with age.

Tansey (1979) analyzed health data from ten years of Polaris sub-

marine medical patrol reports. It was reported that four well-known CAD risk factors are associated with submarine patrols--smoking, high caloric intake, physical inactivity, and high coffee intake. Approximately 60% of the crew smoke, attributing to elevated carboxy-hemoglobin (HbCO) which is known to impair oxygen transport (Bondi, 1978). A high caloric diet of about 3,400-3,600 Kcal per person may influence the level of cholesterol and uric acid. Heavy coffee intake has been found to double the risk for myocardial infarction (Jick, et al, 1973). Lastly, inactivity has been reported to cause deconditioning (Bondi, 1981) and circadian rhythm desynchronization (Schaefer and Clegg, 1966) leading to general physical deconditioning which contributes to fatigue.

6.3 Fatigue, Work-Rest Cycles, and Sleep Patterns in U. S. Navy Submariners.

In 1971, Johnson studied 15 crew members to determine whether fatigue during a patrol affected performance as indicated by a mechanical ability test and a complex tapping test. The results showed that performance was fairly constant throughout the patrol, with a slight improvement in the complex tapping test toward the end of the patrol. It was pointed out that this study lacked proper experimental controls. There was also no mention of the subject's age, rank, duties, prior experience, work-rest cycles, or sleep patterns all of which may have contributed to one's particular performance. Another study by Debell (1969) did, however, consider quality and quantity of sleep, mood patterns, experience and rate of subjects on the score of a complex tapping test. There were no overt changes in this test during patrol.

Circadian rhythms during submarine patrol are of interest to researchers because of the imposed inhabitation in a closed environment, lack of temperature-humidity changes, and abnormal work/rest cycles. In 1968, Messina studied the effects of a submarine patrol on the circadian nature of core temperature, cardiac rate, respiratory rate, blood pressure, urine volume, and pH of urine. Temperature and pulse gave the most reliable data and showed synchronization with the work-rest cycle. In 1979, Schaefer, et al, reported the effects of 18-hour (6 on-12 off) watch schedules on circadian cycles during submarine patrols. His subjects demonstrated 18-hour cycles of body temperature, pulse rate, respiratory rate, and blood pressure. These cycles were superimposed on a persisting 24-hour cycle of the same function. It was observed that certain crew members had problems adjusting to the 6:12 watch cycle. Schaefer contends that these persisting 24-hour cycles may be an explanation for the adaptation difficulties to the 18-hour cycle.

In a recent study, Beare, et al (1981) discuss work-rest cycles and the quality and quantity of sleep patterns associated with them aboard FBM nuclear submarines. Watch standing accounted for 57%-67% of the work time, averaging 8.0 hours/24 hour day on 6:12 cycle and 6 hours/24 hour day on the 6:18 cycle. Sleep times averaged 8 hours per day which has been reported to be a sufficient amount for optimal performance (Johnson and Naitoh, 1974; Naitoh, 1976). Beare concludes that sleep deprivation is unlikely to be a problem aboard an FBM. Sleep patterns aboard submarines have previously been investigated (Colquhoun, et al, 1979;

Schaefer, et al, 1979), and it appeared that the quantity of sleep on FBM's was related to a function of the duty and mission of the submarine. Fragmented sleep does occur aboard the FBM in that a single long episode of sleep is not taken during the same time each day. Beare, et al (1981) have shown that the quality of sleep is not as good as shore duty sleep, but they suggest that sleep quality is not likely a major problem aboard submarines.

Communication with submarine commanders and their personnel has indicated that patrol "staleness" occurs in numerous crew members and as a result, job performance suffers. These commanders believe that this may be, in part, a result of lack of physical activity. This anecdotal evidence does not correlate well with the results of the above studies. Poor design, non-sensitive tests, inadequate subject numbers, or time of data collection are possible reasons for this lack of correlation. More definitive research addressing the problem of performance decrement and novel ways to measure operational efficiency should lead to a better understanding of these much noted casual observations.

7.0 SUMMARY OF SUBMARINE STUDIES

The present submarine environment induces no overt medical problems that hinder the job performance of the typical submariner. This can be attributed to prior research efforts that have identified problem areas and subsequently rectified them. For example, the submarine atmosphere's effect on the submariner's health was a major concern of early nuclear navy investigators. With the present atmosphere cleansing systems, deleterious gaseous contaminants are

virtually eliminated and, although the levels of some will remain above normal air, acute effects on health are insignificant.

The implementation and adherence to a physical fitness program in the Navy have always been considered necessary, however, compliance to the programs have varied greatly from command to command. Specifically, fitness programs on nuclear submarines have almost never been initiated. Early investigators had tried to measure the deconditioning effect on the body during patrol. This research has been inadequate to directly verify the magnitude of the physical deconditioning, and furthermore identify which physiological variables are altered due to the prolonged inactivity periods, e.g, central and/or peripheral. Following present efforts to identify these variables, appropriate exercise (aerobic and anaerobic) programs can be established to maintain physical fitness during patrol.

Recent research showed a 13% decrement of $\dot{V}O_2$ max following a 67-day FBM patrol. This is a significant decrease in cardiovascular function. The implications of this decrement in O_2 utilization to the health and job performance of submariners are not clear at this time. Combined with the frequency of FBM patrols and a continued sedentary life style during shore duty, the aging process and the development of coronary artery disease may be accelerated. Furthermore, this report points out that an unfit individual does not perform mental tasks as efficiently and has a higher level of anxiety than a physically-fit individual. Ultimately this will be reflected in the quality of submariner job

performance. This may be especially apparent when an emergency occurs aboard the submarine, a time when cardiovascular and cognitive functions need to be at peak condition.

8.0 POISITON STATEMENT

We agree that routine aerobic activity as specified by the American College of Sports Medicine has a direct association in the improvement and maintenance of physical and psychological function. Some physical activity can lessen anxiety and depression and improve mental function. Its physiological restorative and health preventative functions are important to submariners.

The closed submarine environment imposes limited activity resulting in physical deconditioning. In addition, the nature of the submarine mission itself leads to somewhat stressful conditions. Limitation of physical activity, desynchronization of circadian rhythms, adverse work-rest cycles, lack of privacy, and altered sleep patterns, may add to the difficulty of obtaining adequate physiological and psychological adaptation during patrol.

It is our opinion that routine physical exercise aboard submarines will prevent physical deconditioning and assist in maintaining psychological well-being. Ultimately the effects on physical and mental fitness will have a positive impact on the morale and operational efficiency of the crew. As a result, the Navy may see a decrease in absenteeism, medical costs, and an increase in morale, job efficiency, physical appearance, and military readiness.

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