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Technical Report

STUDIES OF THE PERFORMANCE CAPABILITIES OF DIVERS: THE EFFECTS OF COLD

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Prepared for:

Dr. James W. Miller
Code 455
Office of Naval Research
Washington, D. C.

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The fortitude of the subjects should not go unnoticed. They subjected themselves to conditions of great discomfort in the interests of the research. While interest competes with discomfort on the first occasion of becoming really cold, enduring the subsequent trials is a matter of determination. Their names are: J. Fucigna, B. S. Stowens, G. V. Guinness, A. Hale, J. Roden, J. Hamilton, and J. Kowal.

ABSTRACT

This study examines the performance capabilities of divers. Trials were conducted at various water temperatures to assess the effects of cold. Dry land trials provided control performance scores. The capabilities tested were; tactile sensitivity, manual dexterity, manual movement, reasoning (arithmetic), problem solving, memory, and a multi-task capability requiring simultaneous manual tracking and attention to an audio channel. The data indicates that diving in warm water causes loss in motor functions due, it is thought, to the changes and hindrances experienced in the diving condition. Diving in cold water increases the motor loss and causes distraction and disruption in mental tasks; "blocking" in attention and lowered memory capability were found. Impairment of performance on the multi-task was considerable. It is hypothesized that cold water stress, in addition to causing specific sensory and motor losses, causes increasing losses of capability as the task becomes more complex and is more dependent on sustained attention and memory functions.

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I. INTRODUCTION

Over the last five to ten years, diving has emerged from its feasibility stage and entered its scientific stage. In previous times, it was a case of admiring the bravery and skill of men operating in the water and lamenting that lack of knowledge and technology restricted what could be accomplished even by courageous men. In recent times interest in and knowledge about the oceans have expanded greatly. This expansion has both inspired and made necessary the placement of men in the oceans to carry out industrial, military and scientific operations. Advances in diving physiology have necessarily led the way. It is now possible to operate men down to depths of 600 feet for extended periods and to assure, with almost complete certainty, the protection of their physiological integrity. This success has led, in natural sequence, to the question of the work effectiveness of the diver. To what extent is his behavioral integrity preserved? and what factors serve to deplete or change his behavioral capacities and in what degree and kind? Knowledge about these issues is, we believe, imperative before a thorough and effective undersea man/machine technology can be developed.

This study makes a beginning toward evaluating the behavioral changes that occur as man enters the water and experiences the chilling of his body which is characteristic of the majority of operational diving situations. That this knowledge is needed is attested by the comment of Mosby (1967) that, in his experience of oil well-head operations, divers on the average are only 10 to 20% as effective as they are on dry land. Some other quantitative and qualitative evaluations of the work effectiveness of divers within the present "state-of-the-art" are provided in our previous publication (Bowen et al, 1966).

The general concern of the present studies is the performance of divers. Our special concern is with the condition of divers being cold. In a previous study (Bowen, et al, 1966) we reviewed briefly the features of existing and working in the water. It will be sufficient to notice here that, even if life support systems maintain the full integrity of physiological functioning, the interface of man with the water environment imposes constraints, stresses, and changes on his behavior. Thus, we cannot study adequately the effects of cold on divers without studying, as a control condition, the effects of immersion in the water at temperatures which do not produce any sensible body chilling.

Our general purpose, then, is to study the course of behavioral change in the diver as he meets the difficuities and adversities of the water environment, and to measure the effect of these changes in terms of task accomplishment.

A review of the psychophysiological effects of cold precedes the description of the studies undertaken. Previous studies mostly relate to cold air and, while providing a basis for understanding the response of the human to cold thermal stress, do not relate to the particular thermal events which occur when man experiences the massive whole-body heat drain which cold water produces. While Beckman and Reeves (1966) have studied the parameters of survival in cold water, there is little data on psycho-physiological changes before body chilling has advanced far enough to make survival an issue. This study begins to fill that gap.

II. PSYCHOPHYSIOLOGICAL EFFECTS OF COLD: A REVIEW

In most studies of the effects of cold, young male subjects were exposed to cold air. Almost all of these studies were concerned with the effects of cold on man's ability to use his hands. Studies have shown decrements in gross measures of task performance, e.g., fewer numbers of items handled per unit time, increased time to complete an assembly task, reduced accuracy in manual tracking, and also losses of specific abilities, e.g., tactile sensitivity, muscle strength, and speed and accuracy of finger, hand and arm movements. Apart from confirming the general finding that low temperature impairs manual performance, many of these studies in cold air are of little direct value to us in our concern with the effect of cold on the performance of divers because they give no data about the temperatures of the subjects themselves. Clearly, it is of little help in predicting the effect of cold on divers to know that men wearing full arctic clothing, except for gloves, perform manual tasks ineffectively out-of-doors at air temperatures minus 20° F and below, or that lightly clothed men work less efficiently indoors at 40° F than at 70° F. Fortunately, a small number of studies have related manual performance measures to hand and body skin temperatures (Clark 1961, Clark and Cohen 1960, Gaydos 1958, Gaydos and Dusek 1958, Lockhart 1966) and we can use their results as guides in predicting performance in cold water.

Skin Temperature and Manual Performance

When hand skin temperature drops to 55° F and below, and the rest of the body is kept warm, manual performance is impaired. Even when the surface of the body was cooled at the same time to an average temperature of 78° F, no additional impairment of performance was observed (Gaydos and Dusek 1958). But in another study (Lockhart 1966), cooling the body surface to an average temperature of 69° F impaired the performance of two manual tasks, even when the hands were kept warm. But the impairment in manual performance associated with a body skin temperature of 69° F was less than the impairment resulting from hand skin temperature of 55° F. The greatest decrement in performance occurred, however, when the subject's body and hand skin temperatures were simultaneously reduced to 69° and 55° respectively. The impairment in performance occurring at a hand skin temperature of 55° F was observed in another study (Clark 1961), the impairment increased up to forty minutes, but no additional impairment was observed up to sixty minutes.

The degree of impairment in performance at a particular skin temperature of the hand depended on the rate of cooling. When the skin cooled very rapidly, the decrement was less than when the skin cooled more slowly. The implication is that, with exposure to very severe cold (e.g., sub-zero air) the temperature of the skin falls much more rapidly than the temperature of deeper tissues, and that maximum impairment of manual performance occurs only when the deeper tissues have also had time to cool to a new steady state.

In moderately cold air (e.g., about 10° F) the bare hand will cool down more slowly and temperatures of the skin and deeper tissues will remain more nearly uniform. Consequently, when skin cools down slowly to 55°F, the internal hand temperatures are also likely to have been lowered sufficiently to hinder performance. Cooling the skin impairs tactile sensitivity (Mackworth 1956 and Mills 1957), while cooling deeper tissues reduces muscle strength (Horvath and Freedman 1947) slows movement of joints (Hunter 1957), and reduces the accuracy of placement and movement of the extremities (Dusek 1957 a&b).

At low temperatures, sinovial fluid that serves as a lubricant for joints becomes more viscous, blood becomes more dense and flows more slowly (even independently of vasoconstriction), and, at temperatures below 48° F, neural conduction is impaired (Edholm and Burton 1955).

Vasodilation in Cold

At initial exposure to cold, vasoconstriction occurs, thereby gaining a degree of thermal insulation at the periphery and conserving body heat. When the skin temperature of the hand in cold air falls to about 50° F, a reflex vasodilation generally occurs (Rubin 1957) that increases the peripheral blood flow and raises skin temperature a few degrees, sometimes followed by vasoconstriction and vasodilation again in a recurring alternating sequence. This reflex vasodilation can occur also at much lower temperatures as, for example, when the fingers or hands are immersed in iced water (Edholm and Burton 1955). The extent of the reflex vasodilation and associated warming of the skin is greatest if the rest of the body is at normal temperatures. The vasodilation of the hands tends to be suppressed if the body is cooled also. In the absence of reflex vasodilation, an immersed part of the body will cool rapidly to the temperature of the surrounding water. Individuals differ in the consistency and rapidity with which they exhibit this cold-induced vasodilation.

The latency of an individual's reflex response to cold has been found to increase when he is threatened with an electric shock, and individual differences in latency were found to be correlated with performances of a "conflict-uncertainty" task (Teichner 1965). Individuals who have long delays or tend not to vasodilate in cold appear as highly or overly aroused individuals in other characteristics. This apparent relationship between arousal (or anxiety) and reflex response to cold could be significant for divers working in cold water under a combination of stressful conditions. If an individual dives in cold water when he is very anxious or otherwise strongly aroused emotionally, he would probably work less effectively and would not be able to tolerate the cold as long as usual.

Cold Acclimatization

People who normally work outdoors in arctic cold have been found to suffer a smaller loss of tactile sensitivity than indoor workers when their fingers were exposed to sub-zero temperatures (Mackworth 1953 and Mackworth 1956). The hands of the outdoor workers did not get as cold as the hands of the indoor workers. Local acclimatization to cold has been suggested as one explanation of this difference, although a self-selective process may have been involved, and possibly the indoor workers were more anxious than the cold-experienced outdoor workers about exposing their bare hands to the very cold air. A more general process of cold acclimatization has been reported among members of polar expeditions. A number of different responses to living and working in the cold have been observed. Individuals have increased their heat production by changes in diet and activity levels, increased their insulation by the addition of body fat, and reduced their blood flow to the skin, thereby lowering their skin temperature and heat loss (Budd 1964).

Adaptation to life in a cold climate undoubtedly involves psychological processes of habituation to the discomfort of cold and learning to perform sensory motor tasks with reduced or modified sensory feedback information (Edholm and Burton 1955). Both of these psychological processes are likely to be important for divers working in cold water.

Complex and Cognitive Tasks

A number of the manual tasks that have reportedly been performed less effectively in the cold were relatively complex and involved numerous perceptual and cognitive elements, e.g., the tuning and operation of radio and radar equipment (Blair and Gottschalk 1947), multidimensional tracking (Payne 1959) and typing (Rohles 1953).

Thus it is possible that the cold exposures had impaired not only the manual elements of these tasks, but also the organization of these elements into a complex activity involving the timing and coordination of responses to changing stimuli. One of the few studies that have investigated the effects of cold on divers (Baddeley 1966) reports that after diving in sea water at 4°C, the divers' judgements of the passage of time were impaired. They judged a significantly longer period of time equal to one minute than they did at normal temperatures. Consequently, an impaired sense of the passage of time might affect the timing of related elements in a complex task.

Simple reaction time tests in still cold air as low as -35°F for men dressed in arctic clothing have revealed no effect of the cold. However, when the air is moving at ten to twenty-five miles per hour, a significant slowing of response has been reported (Teichner 1958). But the fact that the slowing of response was not correlated with lower skin temperature suggested that the effect was not physiologically determined, but possibly due to distractions from wind-produced noise, discomfort and the perceived threat of cold exposure.

One study has reported that an air temperature of -40°F impaired men's visual acuity (Kobrick 1965). However, one wonders if normal visual performance was disrupted by superficial factors such as tearing or compulsive blinking. Since neither facial skin temperatures nor other body temperatures were recorded, it is impossible to relate this finding to the diving situations.

Predicted Effects of Cold on Divers

The most significant difference between air and water, for assessing the effects of thermal stress, is the fact that water is 44 times more heat conductive than air. Also, for practical purposes, the water environment can be regarded as an infinite heat sink. Therefore any exposed surface tissue will tend to take on the temperature of the surrounding water very quickly.

On the basis of the studies reviewed, we would expect divers working with bare hands in water at 55°F certainly to suffer some loss of manual dexterity. As the skin temperature over the rest of their bodies cools to about 70°F, we would expect increased impairment of grosser movements. Divers in cold water will experience loss of tactile sensitivity, accuracy and speed of movement. When deep body temperature starts to fall, violent shivering will start and is likely to interfere further with working ability. In water at about 50° F, vasodilation of cutaneous blood vessels may occur and raise the skin temperature of the hands sufficiently for adequate performance, at least for a short time. But if an individual is anxious or if his core temperature begins to fall, the vasodilation is likely to be suppressed and the hands will cool down to the water temperature. In water at 45° F, or below, the impairment in performance will occur more quickly and reflex vasodilation is unlikely to be sufficient to maintain performance. The loss of sensation from the hands will require greater reliance on visual feedback information to perform manipulative tasks. Consequently, the effects of cool water are likely to be more noticeable in low visibility conditions. Practice in working in cold water should result in restoration of some of the lost manual skill provided some feedback information is still available. The discomfort and pain of the extremities and the chilling sensation of the water on the body are likely to be powerful distractions to attention. Consequently, we would also expect perceptual and cognitive tasks to deteriorate in cold water, and especially tasks that depend heavily on sustained attention and short term memory for their satisfactory completion.

III. PRELIMINARY EXPERIMENT

Purposes

The purposes of the preliminary experiment were to gain experience and develop methodology in conducting experiments underwater, and to measure the changes in tactile sensitivity and manual dexterity between dry land and various water temperature conditions. In addition to the collection and interpretation of data, it was intended that this preliminary experiment would generate guidelines and hypotheses for future experimentation.

Tests

Tactile Sensitivity: "V" Test

Tactile sensitivity was measured using the Mackworth "V" test (Mackworth, 1953). Two upright straight edges were clamped together so that they formed a shallow V; see Figure 1. Divers cooperated in measuring each other's threshold. One diver took the subject's finger in his right hand and, holding the instrument in his left hand, placed the middle of the end joint pad of the finger across the two thin edges of the straight edges. The subject diver cooperated by closing his eyes or looking away and held up one or two fingers to indicate whether he felt one or two pressure points. By progressive bracketing, a threshold was established and then checked by taking confirmatory observations on either side of the threshold point. Threshold was recorded in terms of the distance along the straight edges; this datum was later translated into the gap that was discriminable.

Manual Dexterity: Screw-Plate Test

Manual dexterity was measured by a nut and bolt test; see Figure 2. A 1/16" brass plate, 6" x 6", had 16 holes drilled in it in a 4" x 4" grid pattern on 1-3/8" centers. Eight bolts and nuts were located in eight of the holes on one half of the grid. The bolts were 3/4" long, 1/8" diameter, with round heads 1/4" diameter and 1/8" high; the nuts were hexagonal 3/8" diameter and 3/32" high; the thread was 24 turns to the inch. The test consisted of moving the eight nuts and bolts to the other eight holes in the plate as quickly as possible without dropping the nuts or bolts. The subjects performed the test sitting down and holding an extension of the plate between their closed knees. This test is essentially the same as that used by Baddeley (1965, 1966 b). Baddeley found that this test was sensitive to nitrogen narcosis induced by breathing hyperbaric air, the loss in performance being greater when the subject was actually diving than when

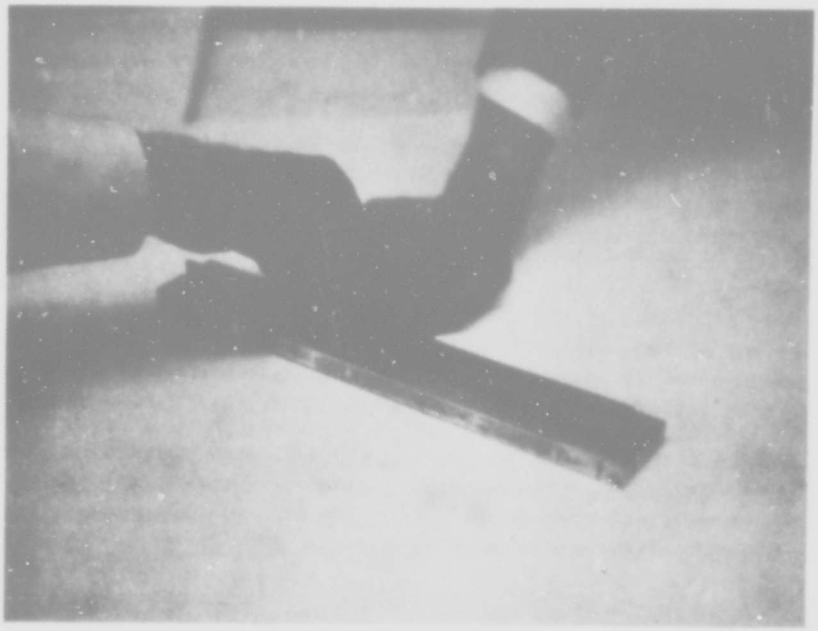

Figure 1. The "V" Test of 2-Point Tactile Sensitivity

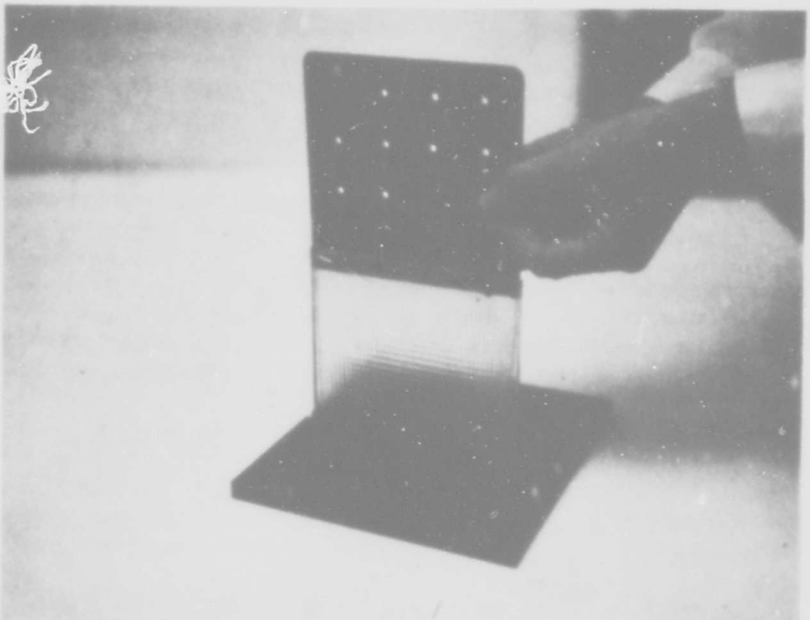

Figure 2. The Screw Plate Test of Manual Dexterity

exposed in a dry pressure chamber. Baddeley reasons that the water condition adds to the impairment brought about by nitrogen narcosis; for discussion of this point, see Bowen, et al., (1966).

Experimental Conditions and Procedure

The tests were performed on a submerged platform in a flooded quarry. Visibility in the water was excellent at the depths utilized (max. 36 feet); visibility was checked by means of a vision chart and on all occasions a 1/100th inch wide white line on a black background was easily visible at a three-foot viewing range. The platform measured 8' x 4' and was stabilized in the water by means of weights hanging from the corners. It was suspended from a derrick and could be raised or lowered at will. It was found that the water temperature decreased fairly uniformly at a rate of 1°F per foot and the platform could be positioned to the desired temperature (down to 44°F) by adjusting its depth. A depth gauge and a water thermometer were attached to the platform.

The experimental subjects were drawn from the professional staff of Dunlap and Associates, Inc. All had received a formal course of training and had some diving experience not exceeding one year in duration or about 50 hours in the water. This relative inexperience of the divers may have influenced the results, possibly in the direction of making the subjects less able to counteract the problems of working in cold water. Hence, the results may exaggerate the effects of cold water on divers' performance and less change would be found if experienced divers were to be used.

Test procedures were as follows: A team of two divers were scheduled for each test run. A minimum of one hour (usually two hours) separated successive runs for the same divers in order to regain normal body heat. The team of two divers dressed in full wet suits; hood, jacket, trousers, bootees, all in 3/16" rubber neoprene material. They donned their tanks with the air breathing equipment, face masks, flippers, and weight belts. Their hands were bare. In this state, they sat down on the edge of the quarry on a wooden platform and performed both tests under dry conditions. As quickly as possible (to avoid becoming very hot) they entered the water and swam down to the platform. From immersion to becoming settled on the platform and ready to start was standardized at two minutes. Each diver carried a screw-plate test plate, and one diver carried the V test and a recording tablet. In order to ensure stability of the divers on the platform, two 20-pound weight belts were attached to the platform and the divers placed them over their laps so that they could assume a steady sitting position. These weights were in addition to the normal belt diving weights which, for the shallow depths used, had to be from 15 to 20 pounds to gain neutral buoyancy.

When the divers were in position and when two minutes had elapsed from entry into the water, they undertook the first run on the screw-plate test. Each diver timed himself on his own wristwatch equipped with a second hand. When both divers were finished, a signal was given by a pull on a rope. The record-keeper began timing a five-minute period. During this first waiting period, the divers checked the readings on the depth gauge and on the thermometer and wrote them down together with the time scores from the screw-plate test. The end of the five-minute period was signalled to the divers on the signal line and they performed the second trial on the screw-plate test. At the end of this trial, another five-minute period began in which the divers recorded their scores and performed on each other the V tactile sensitivity test. After the elapse of this second five-minute period, the third trial on the screw-plate test was conducted. The divers recorded their scores and returned to the surface.

While some variability in this procedure inevitably occurred, the average exposure times to the temperature condition are estimated to have been:

Screw-Plate Test:	1st Run (at halfway point)	2 minutes
	2nd Run (at halfway point)	9 minutes
	3rd Run (at halfway point)	16 minutes
V Test:		12 minutes

The temperatures actually used were 70°, 61°, 54°, 49°, and 44°F. Temperature variation was within ± 1°F from those above, except for the second condition, where the range was from 59° to 63°F; the difficulty here was that a thermocline existed at about 60°, making the placement of the platform highly critical; an inch or two of difference in depth could change the temperature considerably.

Assigning these temperatures the numbers 1 (70°), 2 (61°), 3 (54°), 4 (49°) and 5 (44°), the orders in which the subjects experienced the temperature conditions were:

Subject

A	B	C	D	E	F
3	3	3	1	3	3
4	4	4	3	4	1
2	2	2	4	2	3
5	5	5	5		2
1	1	1	2		4
3	3	3	4		
5	4	5			
2		2			
4		4			

It can be seen that the temperature conditions were experienced in a varied order. Subjects A, B, C, and D performed at least one trial at each of the temperature conditions. Subjects E and F failed to complete one trial at each temperature condition, and for this reason, their data are excluded from the analysis. In part, their incompletions of the trials were due to the inability to perform the runs at the colder temperatures. Subject E was very slow at the Screw Plate Test (he took two to four times as long to complete a run compared to the first four divers) and his performance was seriously impaired at the 49° F condition. Subject F had to discontinue runs before completion at 54° F and 49° F. Subject B also had to discontinue one run at 44° F. While all divers experienced stress in varying degree, the divers who aborted experienced violent shivering ("the shakes") and were in considerable discomfort. The experience of these divers indicates that the colder conditions were close to limiting endurance values and that it may be expected that some persons cannot cope with the degree of exposure used in this study.

Data Analysis: Screw Plate Test

Analysis was performed on the results provided by divers A, B, C, and D. The following analyses were performed:

- Presentation Order. The randomness of order or presentation of temperature conditions was tested with the conclusion that the sequences can be considered random

- Control Scores (Dry Land) Screw Plate Test. The control scores were examined to determine whether they varied significantly as a function of the temperature condition which followed (i.e., there might have been differential anticipatory effects) and as a function of practice. In neither case could trends be found. Hence, the control scores can be treated as a stable indication of dry land performance

- Screw Plate Test Scores as a Function of Water Temperature and Exposure Time. Tests were performed to discover whether performance changed as a function of time in the water. No effects were found. On the average performance after 9 and 16 minutes in the water was not statistically different from performance after two minutes in the water. Therefore, the data from the three tests comprising each run were averaged. The data tabulated on the following page gives the average performance (time for completion in seconds) of each subject at each of the temperature conditions; control scores (dry land) are also indicated. The figures in parentheses indicate the number of trials each entry is based upon.

Subject	Control	Temperature				
		70°	61°	54°	49°	44°
A	57.0 (9)	66 (3)	70 (6)	81 (6)	88 (6)	89 (6)
B	67.6 (7)	73 (3)	79 (3)	95 (6)	104 (6)	118 (3)
C	56.3 (9)	68 (3)	70 (6)	80 (6)	78 (6)	78 (6)
D	70.2 (6)	105 (3)	111 (3)	100 (3)	120 (6)	147 (3)
Means	62.8	77.2	82.5	89.0	97.5	108.0

Mean time of performance varied significantly ($p < .001$) as a function of temperature.

. Relation Between Control Score and Decrement Due to Cold Water. A suggestive feature of this data is the relation between control score and the decrement between the warmest and coldest water conditions. Listing the subjects in rank order of control score performance, the association may be inspected.

Subject	Control Scores	Differences in Mean Scores Between Temperature Conditions 1 and 5
C	56.3	10 Seconds
A	57.0	23 Seconds
B	67.6	45 Seconds
D	70.2	42 Seconds

On this data, the hypothesis is tenable that skilled performance is less impaired by cold temperature than less skilled performance. Provisionally, we might say that skill at a task reflects the individual's capacity for adapting his behavior repertoire to the task at hand and that when the conditions are changed and become adverse, his better powers of adaptation produce a relatively small decrement in performance.

. Performance as a Function of Water Temperature. The data on average performance scores are graphed in Figure 3. In addition to the overall increase in performance time as a function of temperature, three points are worth commenting on.

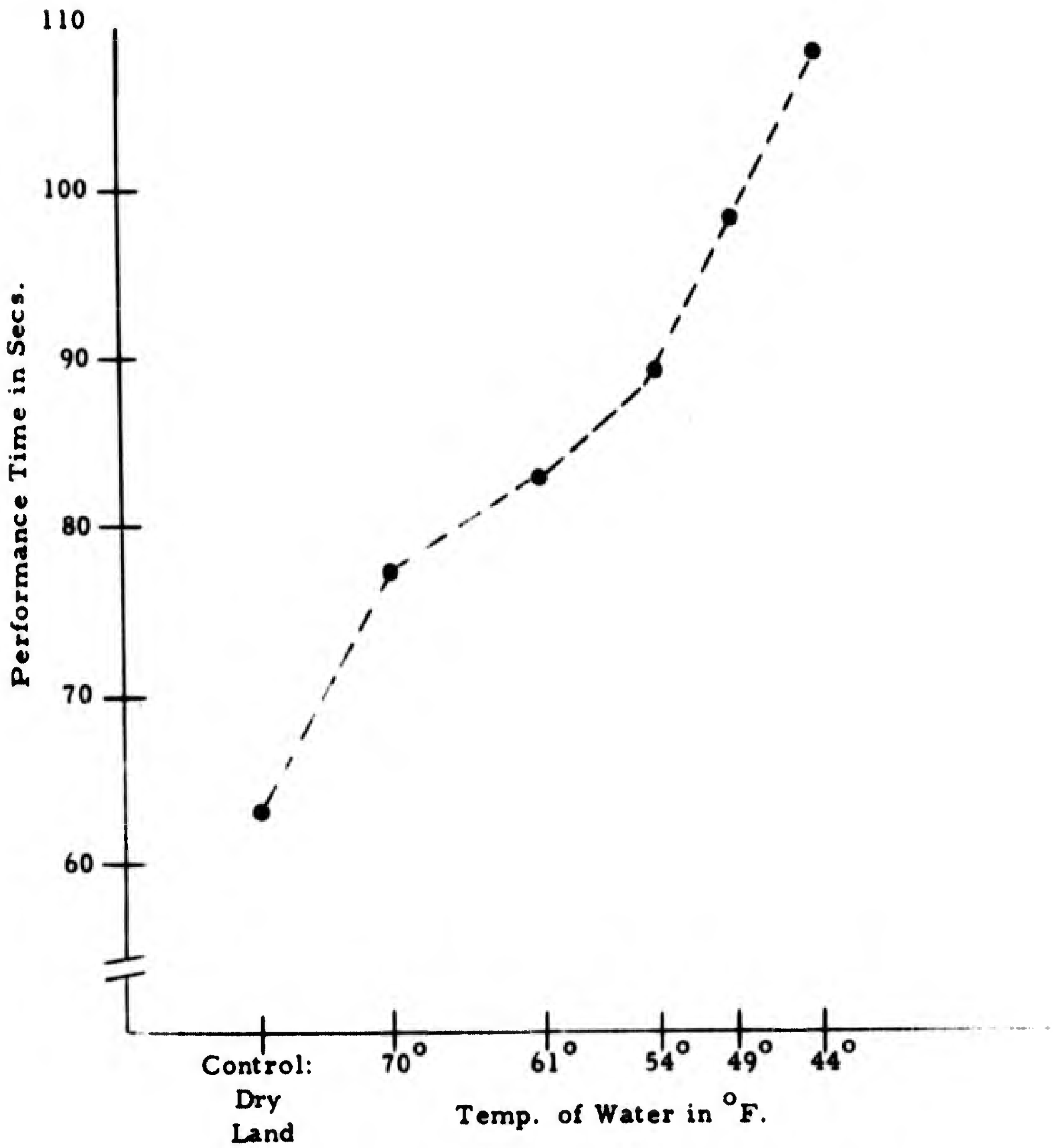

Figure 3. Preliminary Experiment, Screw Plate Test: Average Performance Time in Seconds As a Function of Water Temperature

First, the drop between the control dry land score and the score obtained in the water at 70°F. 70°F water experienced in a wet suit is warm, and the hands suffer only very slight reduction in sensitivity (see later results for the V test). The increase in time of 14.4 seconds (23%) must be attributed simply to being in the water and the various impediments to performance which are thus incurred.

Second, it is noticeable that as temperature decreases, the rate of increase in performance time increases. The data suggest that there may be a point somewhere between 54° and 60°F below which chilling of the hands produces a rapidly increasing crippling of performance.

Third, there is the finding that performance did not deteriorate between the 2nd and 16th minute of exposure, even at the coldest condition. The implication could be that all the detrimental chilling of the hands occurs in the first two minutes or so of exposure, and that body cooling has not progressed far enough by the 16th minute to produce any general effect on behavior. Alternatively, it may be hypothesized that performance is dependent both on the thermal state of the body and on its rate of cooling. Initially, a rapid change of thermal state may cause behavioral disruption; later, behavioral disruption may be due primarily to the lowered thermal state of the body. However, such hypotheses must await more data for proper evaluation.

Data Analysis: V Test

The tactile V threshold measurements were inspected for differences between subjects. There were none; hence, the measurements were averaged across the four subjects.

Control Measurement	Measurement After 12 Minutes Exposure				
	70°	61°	54°	49°	44°
0.13"	0.19"	0.10"	0.21"	0.31"	0.33"

The measurements express the just noticeable gap in inches. A feature of this data is the jump in threshold between 49° and 54°F. It compares to the increased rate of decline in performance on the screw-plate test at approximately the same temperatures. The relative lack of feeling in the hands is a natural reason for lowered performance. Subjective impressions at the lower temperatures were that the hands were numbed and reacted to contact or pressure much more in the mode of pain rather than tactility. The change and attenuation of the sensory feedback requires much more visual monitoring of the actions of the hands and requires an appreciable change in one's approach to the task.

IV. MAIN EXPERIMENT

Introduction

In light of the data and experience gained in the preliminary experiment, the main experiment of the current study was planned. It examines the effects of diving in cold water on a representative sample of psychological functions. It was hypothesized that all psychological functions would show some change or depletion but that the effects would be different according to the type of function tested. In order to simplify this first attempt at a broad assessment of divers' capabilities, it was decided to operate at only two water temperatures--cold (47°F, sufficient to induce considerable thermal stress) and warm (72° F, a comfortable temperature when dressed in a wet suit) in addition to the control condition of dry land. The work site was also changed from the quarry to a tank (which had become available) which would facilitate control over the diving conditions and the conduct of the experiment.

Facilities

The tests were conducted in a tank* 8 ft. in diameter and 25 feet high to the water mark. At the bottom of the tank, a window allowed complete observation of activities in the bottom 6 feet of the tnak. The bottom 6 feet of the tank were floodlit by three 750 watt underwater lamps which provided ample illumination. A metal table and two metal stools were placed at the bottom of the tank so that the subjects could perform the various tests in a normal sitting position. Control desk and diver communicated by underwater hydrophone. Desired water temperatures were attained by filling the tank with cold water and heating it to the desired temperature. The tests were conducted during the winter months, therefore the ambient air temperature tended to cool the water in the tank. Judicious heating, sometimes combined with the removal of some water and refilling with cold, succeeded in gaining the cold temperature (47° F) plus or minus one degree and the warm temperature (72° F) plus or minus two degrees.

*The tank is part of the facilities maintained by Marine Contracting Inc., Southport, Connecticut from whom it was rented for the conduct of the tests.

Diving Procedures

Each diver, when prepared to dive, wore a 3/16" neoprene wet-suit consisting of bootees, trousers, jacket, separate hood, and diving gloves. He breathed air carried on his back from standard 72 cu. ft. tanks. The weights on his weight belt were sufficient to provide strong negative buoyancy. In addition, while performing the tests, most divers also found it comfortable to place their feet into deep sea weighted divers boots and to put an extra weight belt over their laps or shoulders in order to gain stability when doing the tests.

When a diver (or divers when two men were scheduled to perform tests together) was ready to descend, the signal was given for "splash-in" and, as the diver entered the water, a clock was started. Each diver descended to the bottom and established himself there as quickly as possible. The divers aimed to be ready to start tests within 3 minutes of splash-in. However it happened fairly frequently that a longer time was required before a diver had his equipment and himself readied for undertaking the test schedule. At the 3 minute mark, or as soon thereafter as the diver was ready, the diver was instructed to remove his gloves. Thirty seconds was allowed for this operation at the end of which the diver began the first test. Over the next 27 minutes he performed a scheduled sequence of tests so that the total exposure was, nominally, 30 minutes.

As with all diving operations, considerable safety precautions were taken. Those that affected the course of the tests were (1) a diver ensured that before starting a test run he was comfortably seated, all equipment was functioning properly, and that he was free to ascend immediately without hindrance or danger of entanglement (2) after 15 minutes the diver was asked if he was O. K. and was required to check his overall status and (3) the controller, who observed the diver directly through the window, had the responsibility of ordering the diver to ascend should the diver, in his opinion, be in an unsafe state. One diver, after about 25 minutes exposure to 47°F, was ordered to discontinue the test and ascend because he was observed experiencing very violent shivering, was pale, and in general appeared to be suffering severe stress. Various other aborts occurred from time to time for a variety of reasons.

Each diver made either one or two dives per day, generally two. The separation between dives was never less than two hours and normally was between 3 and 4 hours. In between dives, the diver took a hot shower, dressed in dry warm clothing, availed himself of a heated rest room equipped with bunks, and took hot drinks and food as he might wish. Divers, after experiencing the cold test condition (47°F), found that they remained chilly for about one hour, were hungry and thirsty, and fell asleep easily.

Subjects

The subjects were five staff members of Dunlap and Associates, Inc., who volunteered for the project. The age range was 24 to 41 years. Experience in diving was: one man, 10 years of scientific and recreational diving; one man, 2 years scientific and recreational diving; three men, an intensive training course in Scuba providing about 12 hours water time just prior to the study. All subjects had been screened by a medical examination and were in physical condition normal to conventional domestic and office life patterns.

Test Sequence

The basic test sequence during each 30 minute trial and after "gloves off" was for a diver to undertake Test A, Test B, Test A, Test B. Thus each diver performed two tests twice; each test was scheduled to start at a precise time so that time exposure to the water conditions was controlled. Each diver did each test twice for the three test conditions, namely, dry land, 72° F wet, and 47° F wet. The sequence of testing was varied so that sequence effects were entirely counterbalanced. When the "V" test of tactile sensitivity was scheduled, the test was performed immediately after "gloves off" and, secondly, at the very end of the trial. For the majority of the trials, it was practical to use two divers simultaneously (which was in any event necessary for the tactile sensitivity test). One diver performed Test A while the other performed Test B, they then exchanged tests three times to complete the trials.

Thus each test was performed by each diver twice in the first 15 minutes of exposure, specifically, once in the first part and once in the last part of the 15 minute period. The procedure was repeated in the second 15 minutes of exposure. As each diver performed these trials twice for each condition (dry, 72° F, 47° F), each test was performed four times for each condition but at differing exposure times. Exposure time is counted from the mid-point of the 30 seconds "gloves off" period.

The Tests

The tests ranged across a representative sample of psychological functions and were designed to measure the depletions or changes in behavior which occur as man dives in cold water. The functions tested were those often incorporated within normal diving activities. Design of the tests emphasized simplicity and reliability and permitted, as far as possible, self-administration of the tests. Also kept in mind, was the desirability of using the tests in some future diver test battery, perhaps under open-sea operational conditions.

- "V" Tactile Sensitivity Test: the same as described previously for the Preliminary Experiment

- Manual Dexterity: Screw Plate Test: the same as described previously for the Preliminary Experiment except that the plate was mounted on a base so that it would rest stably on the table in an upright position

- Manual Movement: Peg and Ring Test: the test was designed to evaluate a form of manual dexterity which emphasizes whole arm movements. It consisted of a two-foot square board with 16 1/2" diameter pegs protruding from it in a 4 x 4 grid on 5" centers. An upright peg in front of the board had sixteen 3" diameter rings placed around it at the start of the test; see Figure 4. The task was to place one ring on each of the pegs and then remove all the rings back to the single upright peg. The subject worked with one hand. The score was the time to perform the task.

- Reasoning: Arithmetic Test: the test measured the ability to do a familiar and routine cognitive task which requires the manipulation of symbols in a deductive manner. The subject added and subtracted three digit numbers. Each problem was in the following form:

$$\begin{array}{r} 789 \\ + \underline{123} \\ \\ - \underline{456} \\ \hline \end{array}$$

The subject performed the addition and then the subtraction and did as many problems as possible in three minutes. The problems were printed on a 12" x 12" plastic sheet; the subject wrote his answers in grease pencil; see Figure 5. Scoring was in terms of the number of problems attempted and number correct; the analysis was refined by enumerating the errors in terms of additions and subtractions. Three sheets were prepared and the subjects started at different locations on the sheets to minimize specific learning.

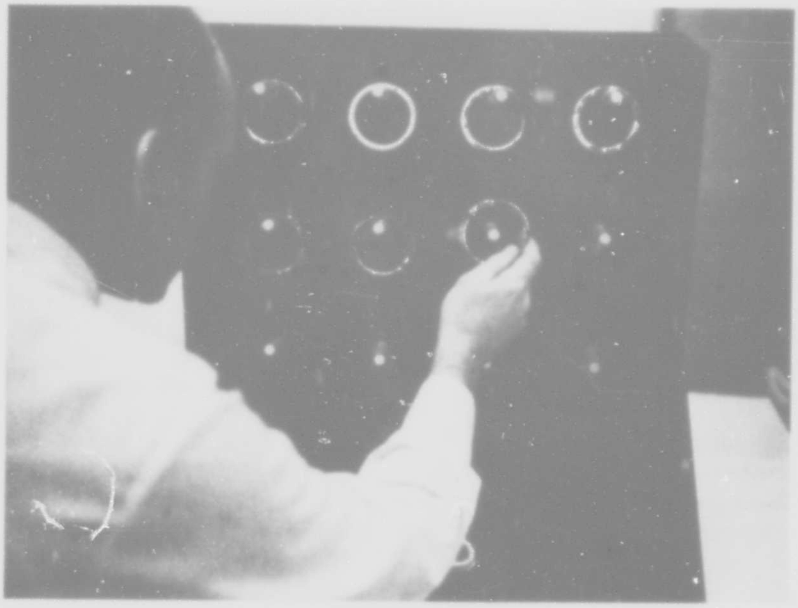

Figure 4. The Peg & Ring Test of Manual Movement

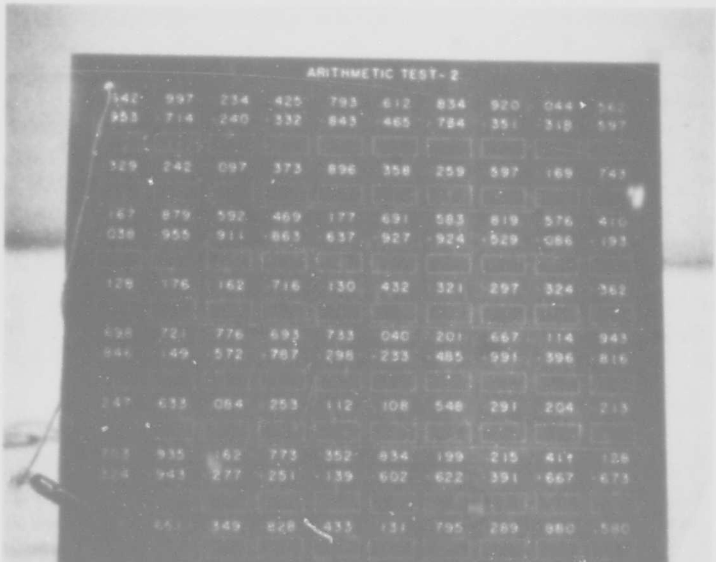

Figure 5. The Arithmetic Test of Reasoning

. Problem Solving: Set Exceptions Test: this test required the subject to discover which one of five items differed from the other four. Solving each problem involved some mixture of deductive and inductive reasoning. The problems were printed on a 12" x 12" sheet in sequence. The subject, using a grease pencil, indicated his answer by striking through one of the numbers; see Figure 6. Each problem was in the following form:

70 105 10 42 21

The answer to the problem is 10, which is the only number not having a common denominator (other than 1). It will be noticed that three of the numbers are divisible by 2, three by 3, three by five, and four by 7. All problems were generated according to this scheme using the divisors 2, 3, 5, 7, and 11. Three sheets were prepared and the subject started at different locations on the sheets to minimize specific learning. The subject had three minutes to do as many problems as possible. Scoring was in terms of number of problems attempted, number correct, and number omitted from the sequence of problems.

. Memory: The Clock Test: this test required the subject to inspect a panel, remember what he saw, and to record as much as he could remember. The panel displayed eight clock faces with movable hour and minute hands. Each clock face was marked in the numerals 1 through 12 and was 3 1/2" in diameter. The faces were marked on a board in two rows of four with 5" between centers; see Figure 7. Predetermined times were placed on the clock faces. The times were random with the restriction that the minute hand occurred only at 15, 30 or 45 minutes past the hour. The subject inspected the board for 1 minute, waited for 30 seconds, and then recorded his recall in 1 minute by marking with a grease pencil, hour and minute hands on a smaller but similarly laid out board. Scoring was in terms of:

- number of recalls attempted
- number recalled correctly
- number recalled correctly but misplaced
- number recalled partially correctly

Figure 6. The Set Exceptions Test of Problem Solving

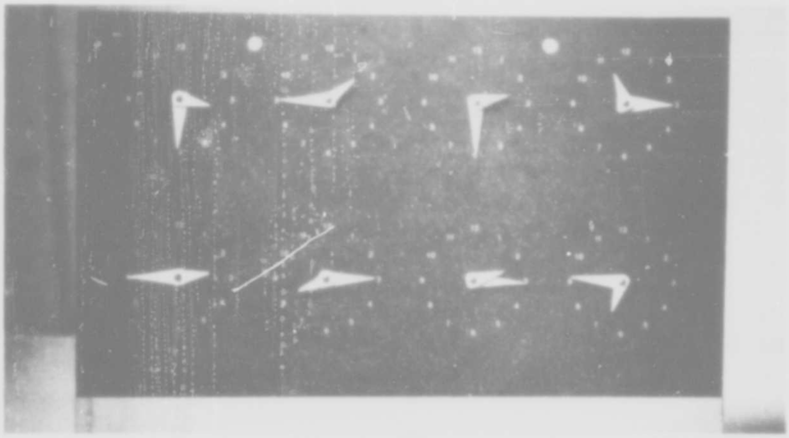

Figure 7. The Clock Test of Memory

. Multi-Task: The Two-Handed Tracking and Audio Vigilance Test: this test required the subject to perform a continuous tracking task and to listen for a specified signal in a continuous stream of signals at the same time. The task may be likened to controlling a vehicle while attending to some message flow. It required the time sharing of attention and the exercise of considerable sensory-motor and perceptual skill.

The Two-Hand Tracking Test developed for SeaLab II was utilized; see Figure 8. The subject moved a peg mechanically along a twisting track by appropriate rotation of two knobs which moved the peg in the X and Y coordinates. The time to move the peg along the length of track was timed. As soon as the peg reached one end, the subject began to move it back along the track to the other end.

The listening "vigilance" task consisted of listening to a random series of two-digit numbers. The numbers were spoken at the rate of one every 1 1/3 seconds and recorded on tape. In the ten-minute period of a test run, 18 of the numbers were repeated in immediate succession. These repeats occurred at random locations in the sequence; see Figure 9. The subject had to detect these repeats. Ten tapes were made to eliminate learning.

Each trial lasted for ten minutes. The subject was scored in terms of the lengths of time required to move the peg along the track, the number of signals that he failed to notice, and the number of times he gave a false positive response.

Program of Testing

After initial set-up, preliminary trials, and practice at the tests covering three days, the tank was established at 72° F. During the next four days all the trials for this condition were run. Whenever possible, dry land control scores were obtained immediately before a wet trial. After the lapse of one week, the tank was established at 47° F and the trials for this condition were run in the same manner, a dry land trial preceding each wet trial.

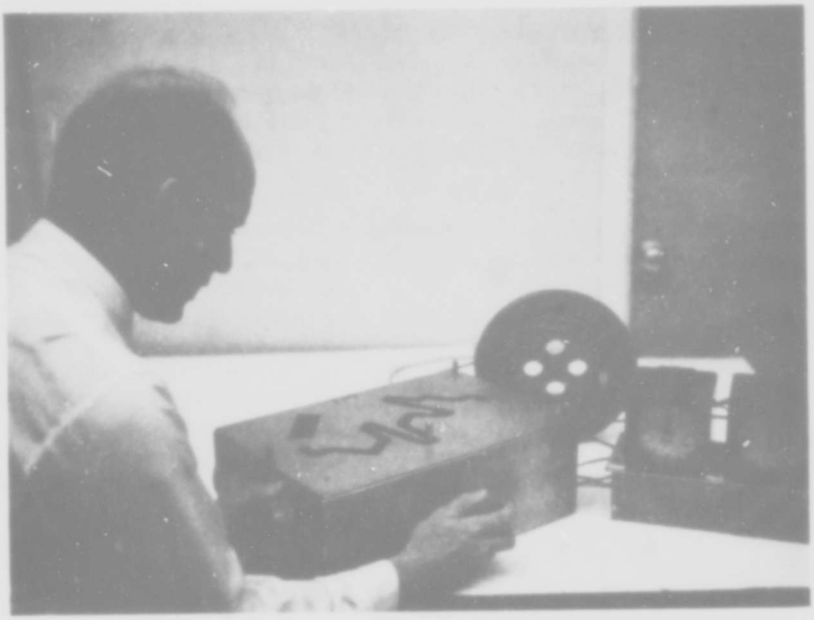

Figure 8. The Two-Hand Tracking Device Used in the Multi-Task Test; Clocks Record Time To Move Peg from One End of Track to Other

Auditory Vigilance List #6

Name ______________________________ Date _______________ Condition Dry 72° 47°

Site ________________________________

81	37	77	62	32	85	63	$\boxed{32}$	79	72	43	93
74	46	86	46	32	76	51	25	36	34	37	78
38	69	57	91	37	45	66	82	65	41	62	33
$\boxed{51}$	62	63	94	48	33	59	93	46	27	82	78
71	37	78	93	23	47	71	44	32	31	96	93
68	84	67	36	93	71	34	98	$\boxed{53}$	93	$\boxed{31}$	75
59	99	67	96	45	86	24	22	38	62	32	53
78	$\boxed{67}$	75	38	62	24	38	88	74	47	49	26
54	29	74	91	$\boxed{41}$	91	68	86	55	77	42	55
26	39	88	76	82	28	83	49	36	33	27	57
87	21	32	54	52	96	34	76	22	$\boxed{59}$	39	59
$\boxed{39}$	59	44	32	44	31	24	74	72	94	26	55
35	76	86	52	76	98	22	42	76	33	43	72
85	33	58	46	45	25	47	92	52	83	98	33
54	78	56	51	95	$\boxed{41}$	35	94	31	89	48	37
36	38	44	33	73	84	85	94	37	24	66	46
$\boxed{92}$	65	21	53	74	43	82	78	29	92	55	27
43	57	54	44	58	32	96	58	77	88	$\boxed{53}$	87
66	34	24	42	57	29	56	$\boxed{91}$	48	37	22	43
49	89	63	85	36	89	48	29	46	69	45	51
59	21	53	43	25	42	27	45	72	53	98	54
$\boxed{79}$	45	44	52	76	45	26	27	68	86	62	85
36	62	83	$\boxed{74}$	99	31	37	32	24	88	23	84
83	44	99	55	93	86	35	97	94	99	38	68
97	38	48	27	57	49	47	52	58	29	94	25
97	82	45	53	35	51	$\boxed{97}$	26	83	26	92	$\boxed{39}$
66	23	93	85	74	77	27	68	54	58	$\boxed{45}$	75
51	55	52	37	95	67	91	56	44	29	96	99
62	94	89	79	$\boxed{54}$	49	34	52	73	64	72	79
42	29	21	46	24	72	88	97	55	49	96	73

Figure 9. Audio Vigilance: Sample Stimulus Sheet: Circled Numbers were Repeated

At the end of this week, the data was consolidated and inspected. From inspection some of the data appeared inconsistent and influenced by practice effects. Therefore after a lapse of three weeks, some of the trials were repeated. The tank was set at 47° F for two days and then 72° F for a further two days. Subjects undertook dry land control trials and wet trials on the Clock Test and the Multi-Task Test (Two-Hand Tracking and Audio Vigilance). Each trial was conducted as before i.e., Test A, Test B, Test A, Test B.

Results

Introduction

The data is presented here in descriptive form. Detailed statistical analysis will await completion of the next phase of testing, using the same and additional subjects. More subjects and a larger number of observations will provide a more adequate data base for the extraction of statistical inferences.

"V" Test

In addition to the dry land readings, "V" test measurements were taken at 1 1/2 minutes after "gloves off" and 24 minutes after "gloves off." * The data is presented in Figure 10. Each point is an average of twenty observations, four for each of the five subjects. It can be seen that the means are very similar except for that corresponding to long exposure at 47° F. The threshold measures are somewhat smaller than those found in the Preliminary Experiment. The differences may have been due to the use of a slightly different instrument or to the greater practice afforded to the present subjects (only one of whom was common to both groups). However the general trend is the same. Tactility under-

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*These exposure times are average. For each test, exposure times are given. Exposure time is calculated from the mid-point of the "gloves off" period to the mid-point of the test period. While each 30 minute trial was scheduled rigorously, a trial seldom went precisely as planned. The variance from the average values given is about one minute for tests occurring near the start of the trial period and about two minutes for tests occurring near the end of the trial period. It should also be remembered that the diver had been immersed with gloves on for at least three minutes prior to the "gloves off" point. The range of this pre-exposure was from 3 to 10 minutes, and averaged about 5 minutes. There is a problem in handling this initial exposure period when the diver (or worse, two divers) is achieving a ready-to-test status. It is not a negligible problem because some of the performance data indicates that some decrements occur very quickly when the diver is exposed to cold water.

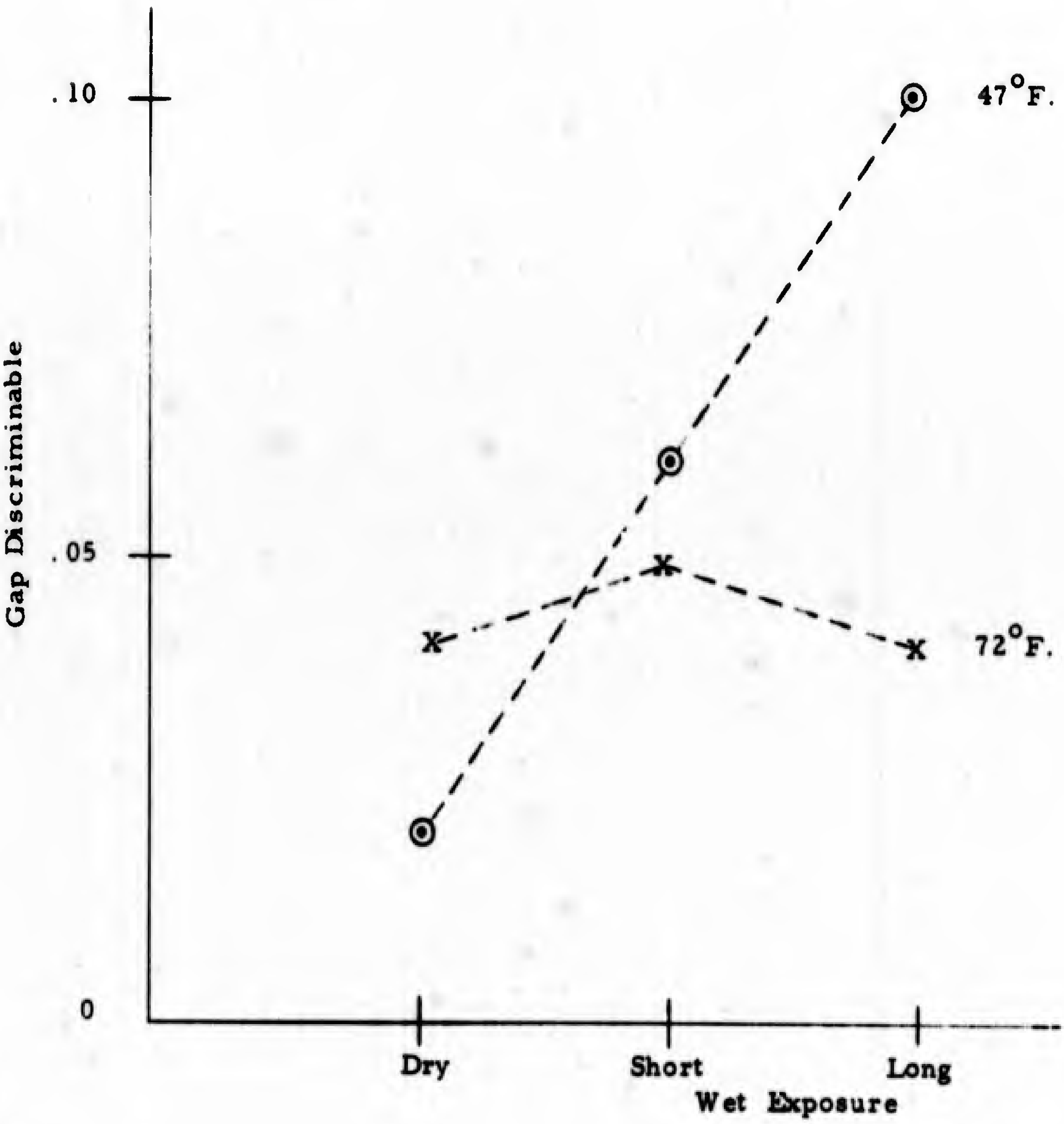


Figure 10. Tactile Sensitivity: Average Threshold Values

goes little change at 72° F, but deteriorates after considerable exposure at 47° F. There is some ambiguity about the data in that the dry land measures associated with the 47° F trials are lower than those associated with the 72° F trials. This effect may have been due to practice. It will be remembered that the 47° F trials were performed after the 72° F trials. Thus, regarding the data for 47° F only, it does appear that even a short exposure of the bare hands to 47° F water reduces tactility. The subjective experience would reinforce this hypothesis for all divers found the initial exposure painful and thought the initial impairment of the hands was rapid and large.

Screw Plate Test

The average exposure times for the mid-point of the Screw Plate Test were 4, 9, 14, and 18 minutes. Inspection of the data indicated that there were no difference in the scores (time to accomplish) between the scores associated with 4 and 9 minutes exposure and between the scores associated with 14 and 18 minutes exposure. Therefore, for purposes of reporting, the 4 and 9 minute exposure scores have been pooled and called "Short Exposure Scores" and similarly the pooled 14 and 18 minute exposure scores are called "Long Exposure Scores."

The data is shown in Figure 11. Two features are worthy of note. First the "water effect" shown by the increased time scores for short exposure scores over the dry land scores, in particular for the 72° F condition. This increase cannot be explained prima facie by attributing it to cooled hands; firstly, because the tactile measure showed no corresponding decrement and secondly, because none of the subjects reported feeling their hands to be the least bit cold. Presumably the impairment comes about from hindrance factors derived from just being in the water. Secondly, there is a "cold effect" as shown by the increased scores associated with long exposure at 47° F.

Comparable data from the preliminary experiment is shown to indicate the degree of reliability of the test. The data is for an exposure time of 12 minutes at 70° F and 49° F. Only one subject is common to both experiments which were conducted under appreciably different conditions.

We note, as a negative finding, that unlike the data from the preliminary experiment, there is no systematic relation in these scores between level of dry land performance and the decrement caused by exposure to cold water. It should be recognized, however, that the sample used in these experiments is too small to deny or affirm the hypothesis with any confidence.

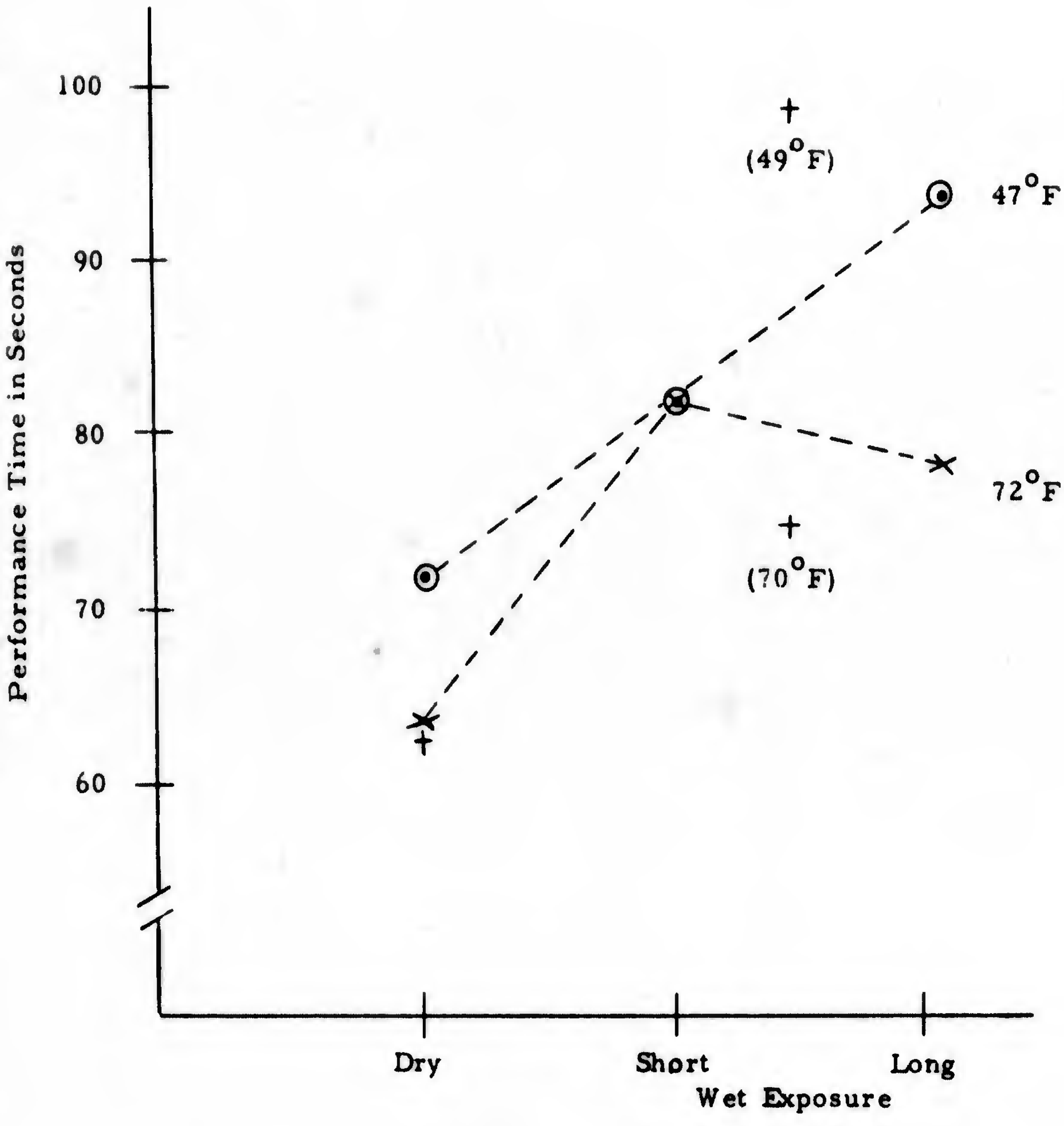


Figure 11. Manual Dexterity: Average Times to Perform the Screw Plate Test: Comparable Data From Preliminary Experiment (exposure period 12 minutes) shown by +

Peg and Ring Test

The average exposure times for the mid-point of the Peg and Ring Test were 4, 9, 15, and 18 minutes. The scores were pooled into Short and Long Exposure Scores for the same reasons that this was done for the Screw Plate Test scores.

The data is shown in Figure 12. The upward trend of the lines suggest, as with the case of the Screw Plate Test scores, a "water" effect and a "cold" effect.

These three tests of simple sensory and motor functions indicate the effects of direct impingement of the thermal condition on the person. He feels less and he works more slowly. Subjectively the motor tasks became more difficult for the reasons that positive grip was reduced, the hands were painful and numb, and the tasks depended increasingly as time went by on control by the visual sense rather than by the combination of visual and tactile senses(and, to some degree, by the general proprioceptive sense). These various depletions seemed, to the subjects, to necessitate performing the tasks in appreciably different ways; it is as though one is directing and controlling a somewhat different mechanism to achieve the same ends.

Arithmetic Test

The average exposure times for the mid-point of the Arithmetic Test were 2 1/2, 4 1/2, 18, and 30 minutes. The scores were pooled into Short and Long Exposure Scores for the same reasons as before.

The data is shown in Figure 13, a, b, c, d. Figure 13 a shows that fewer problems were attempted in the cold condition. This result, in the opinions of the subjects, was due to the difficulty of writing. In addition to the hand becoming cold and less motile, the grease pencil at these temperatures became hard and was difficult to write with. There was also a drop in number attempted from dry land to the water condition at 72° F; this effect is what we have referred to as the "water" effect and is due, presumably, to general hindrance factors probably mostly affecting the motor component of the response. Figures 13 b, c, d indicate that there were only small differences in the accuracy of performance and that errors were not associated systematically with conditions except for the suggestion that errors of subtraction may occur more frequently in the water condition. Overall, therefore, the results indicate that while fewer problems were attempted, those that were attempted were accomplished with high accuracy even under the cold water condition.

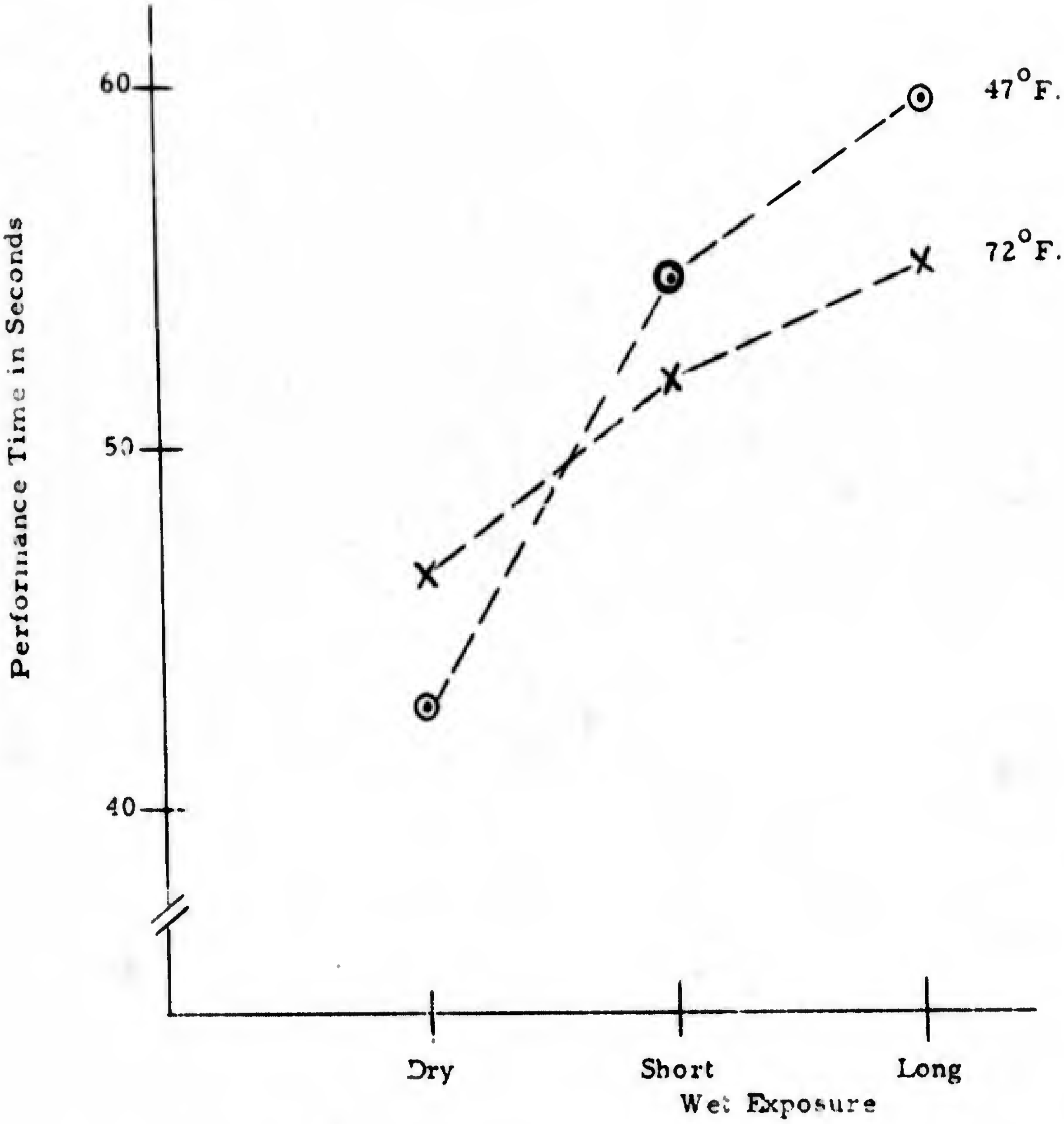
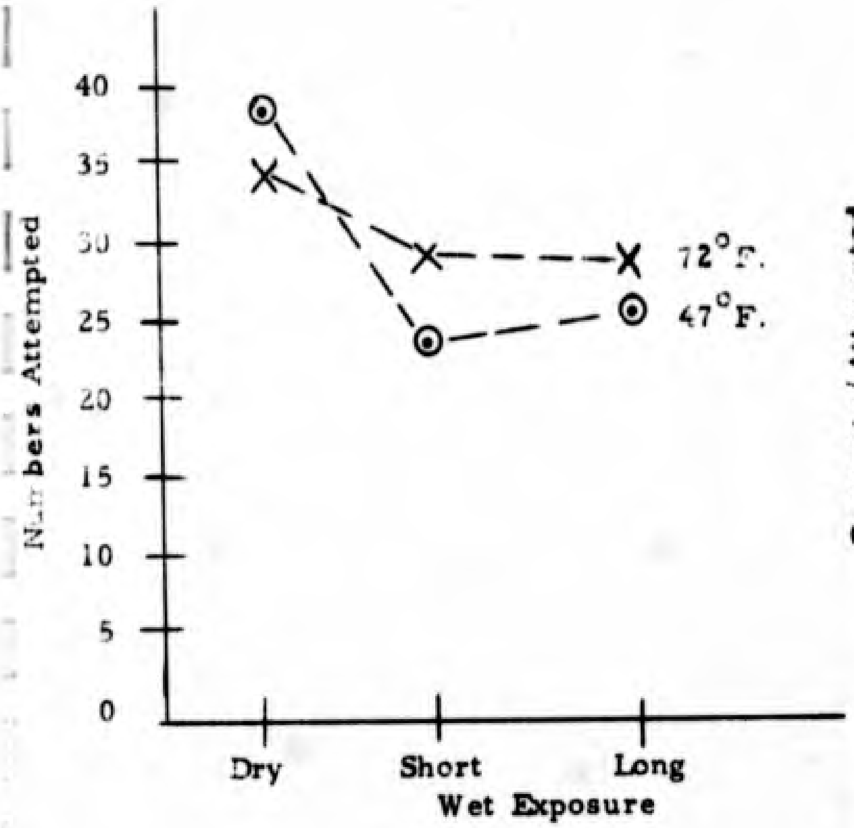
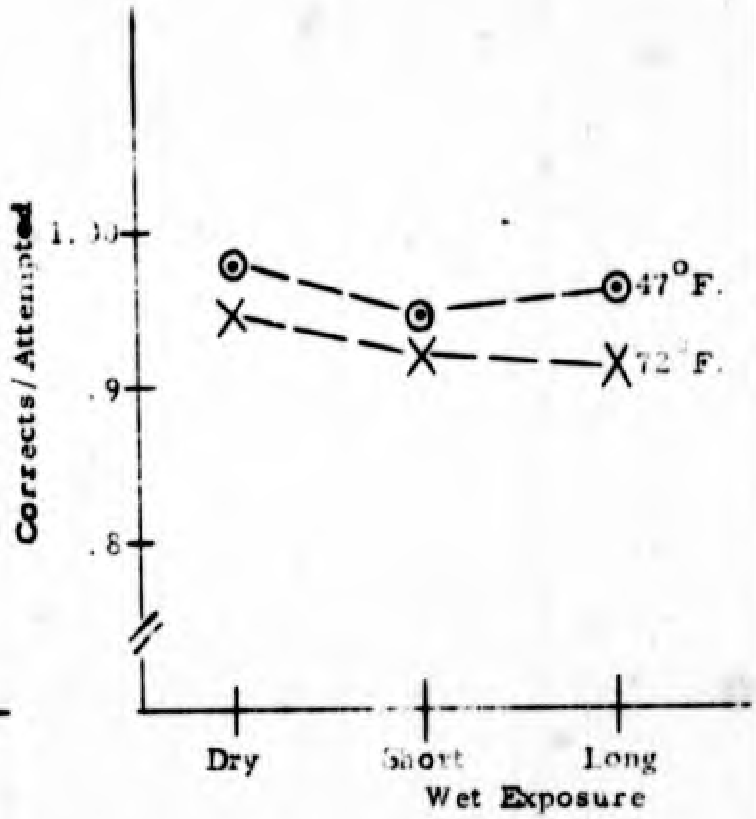


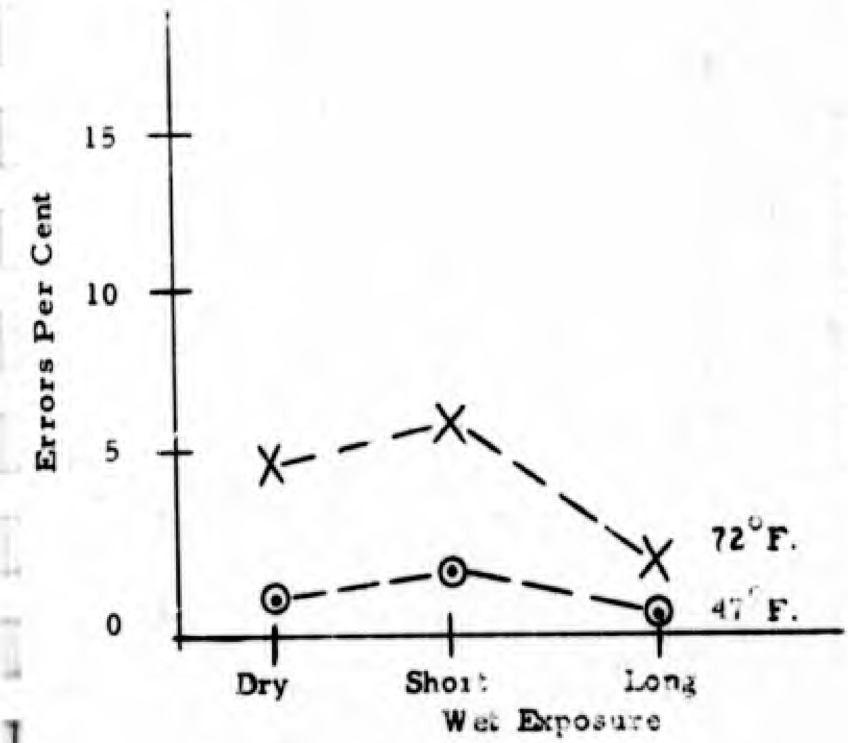
Figure 12. Manual Movement: Average Times to Perform Peg and Ring Test



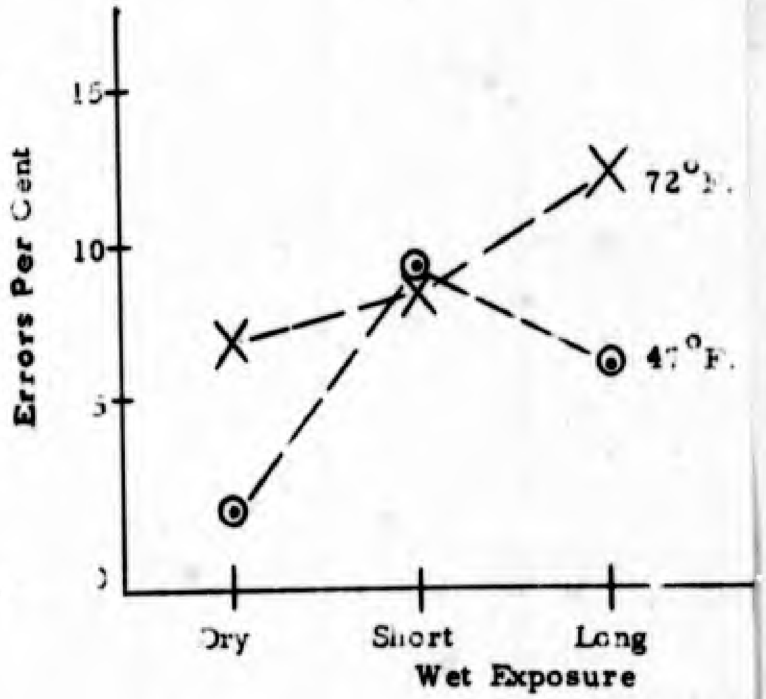
(a) Average Number of Problems Attempted.



(b) Average Ratios of Corrects/Attempted



(c) Average Per Cent Errors In Addition.



(d) Average Per Cent Errors In Subtraction.

Figure 13. Reasoning: Arithmetic Test

Set Exceptions Test

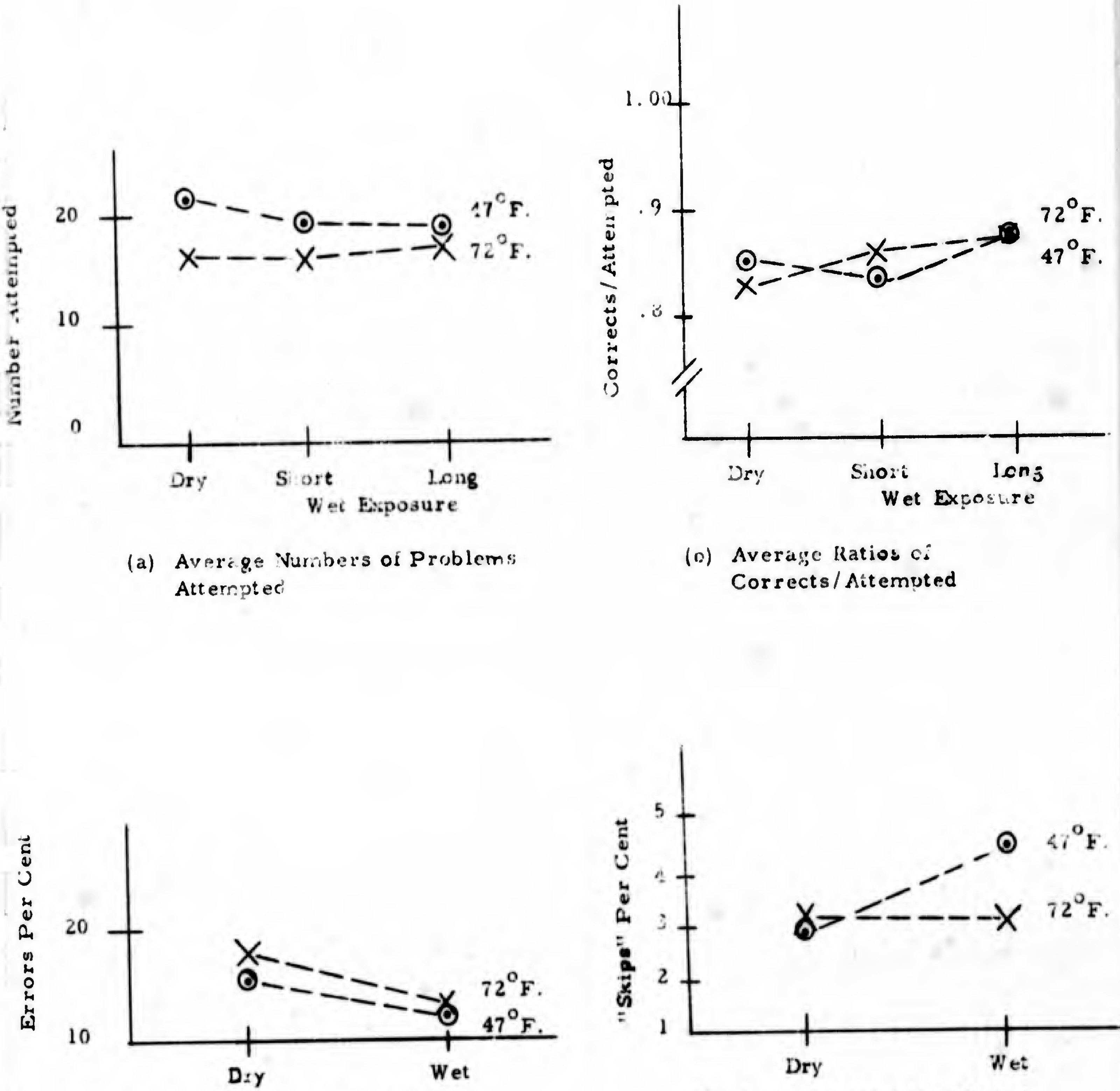
The average exposure times for the mid-point of the Set Exceptions Test were 5, 10, 15 and 19 minutes. The scores were pooled into Short and Long exposure scores for the same reasons as before. The data is shown in Figure 14 a, b, c, d.

In this test, the number of problems attempted increased for the cold water condition; however the increase may be attributed to practice when it is noticed that the dry land trials also show the same effect. Accuracy of performance shows no difference between the different temperature conditions. Cold temperature, in fact, affects this test in only one apparent way; which is that it induces more "skips." A "skip" is where the subject failed to respond to a problem in the sequence of problems and went on to the next one. Subjectively the feeling was that one had tried all the possible ways of solution and none of them worked; one "blocked" in the sense that sufficient flexibility and/or motivation was not maintained to try again; rather than perseverate with a seemingly intractable problem one chose to go on to the next problem.

Clock Test

The average exposure times for the mid-point of the Clock Test were 5, 10, 16, and 19 minutes. The scores were pooled into Short and Long Exposure scores, as before. This test was conducted twice. The data from the first trials indicated strong practice effects (more attempted in the cold water condition than in the warm water condition) and considerable inconsistency in performance. While the data did show that the cold condition produced lower retention, it was felt worthwhile to repeat the test in the hope of gaining more stable results.

On the second trials, each of the five subjects performed the test twice for each condition. The data is shown in Figure 15 a, b, c. Stable performance occurred as shown by the correspondence of the performance figures for the dry land trials. At the colder temperature in the water fewer recalls were attempted, and of these fewer recalls more were incorrectly remembered. The data was scored also for "misplacements" and "partials." A "misplacement" occurred if a correct time was recalled but its position was incorrect. A "partial" occurred if only one hand of the clock was recalled correctly (and in the correct location). These responses may be thought to reflect "confusion" on the part of the subject in attempting to commit to and then extract from memory. It can be seen in Figure 15 c that this "confusion" increased with the adversity of the condition. It is reasonable to conclude from this data that it is more difficult to observe, remember, and report a situation when diving, particularly in cold water. Subjectively,



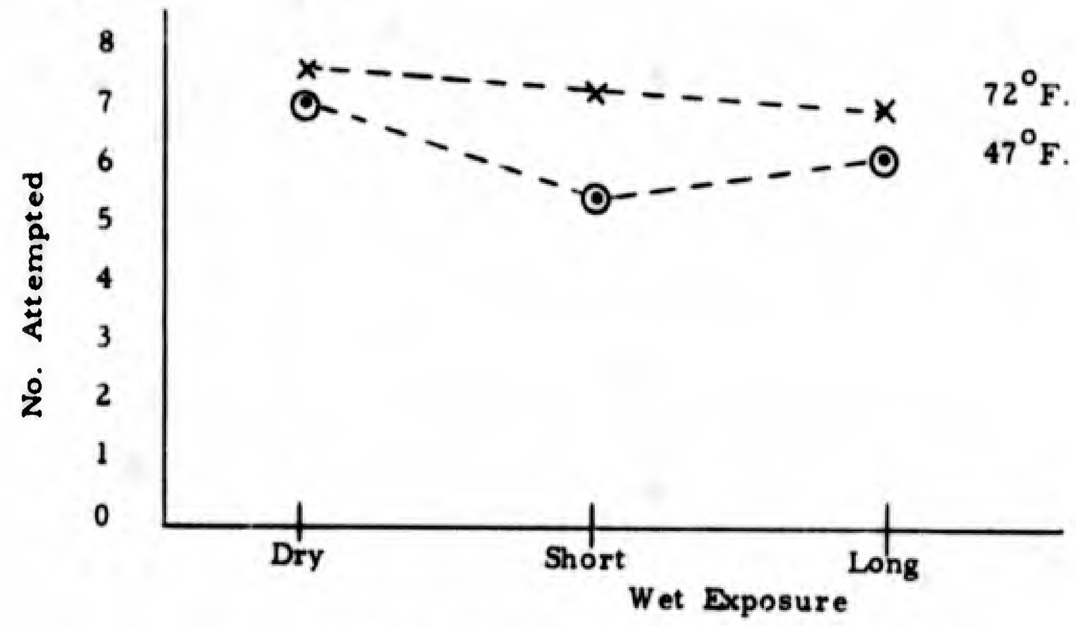
(a) Average Numbers of Problems Attempted

(b) Average Ratios of Corrects/Attempted

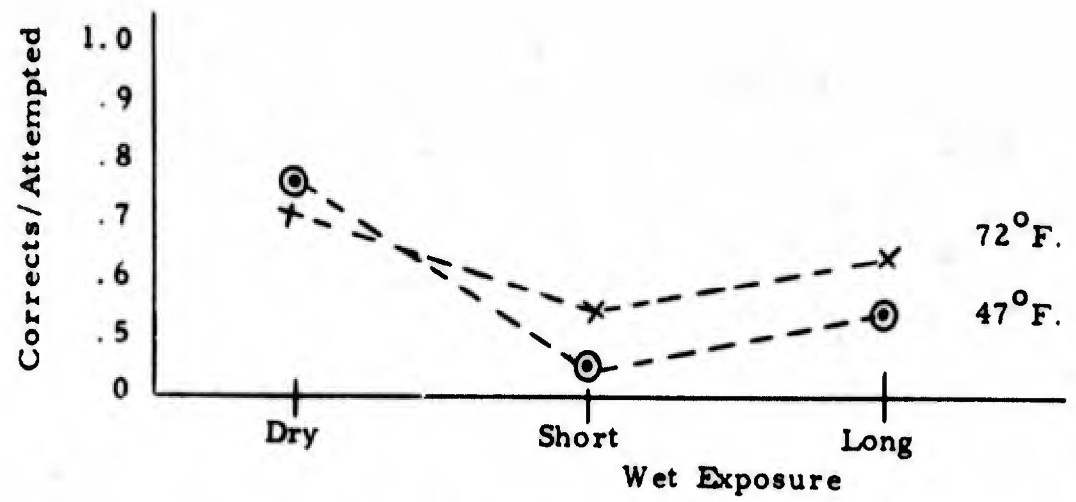
(c) Average Per Cent Errors

(d) Average Per Cent "Skips"

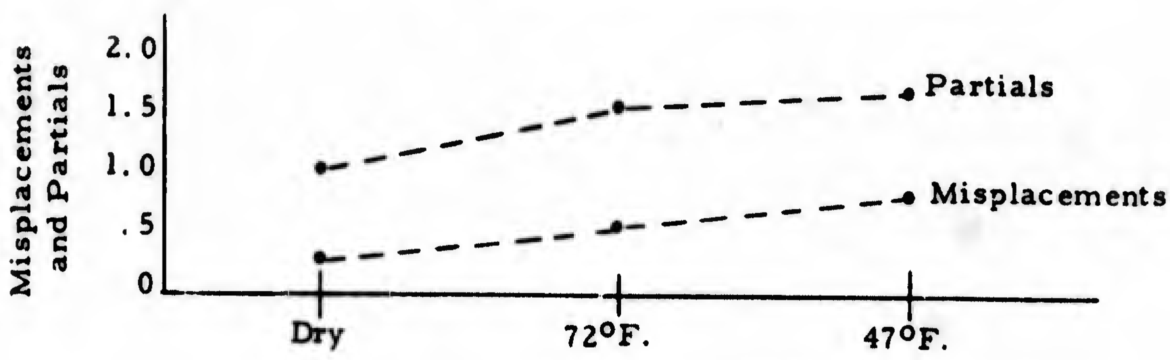
Figure 14. Problem Solving: Set Exceptions



(a) Average Numbers of Problems Attempted



(b) Average Ratios of Corrects/Attempts



(c) Frequency per Trial of "Misplacements" and "Partials"

Figure 15. Memory: Clock Test

it felt difficult to concentrate on the task and to exclude capture of one's attention by the stimuli deriving from being in the diving state and from being cold. One was distracted from and disrupted in the task.

Reviewing the three tests devoted to cognitive functioning -- the Arithmetic, Set Exceptions and Clock Tests--it can be seen that each is impaired by the cold diving condition but in different ways. Simple reasoning (arithmetic) is not impaired in itself because accuracy of performance was retained; rather it was the expression of the mental function in motor acts that was impaired. Problem solving was only a little impaired (fewer attempted) but seemed to be subject to "blocking" effects when performed when the subject was most cold. To the extent that this effect was a consequence of the distraction and disruption caused by the thermal stress, the same effects are indicated by the memory test in more marked degree. A general loss was found both in memory span and retention accuracy. The data indicates a growing amount of memory confusion as the conditions become more adverse.

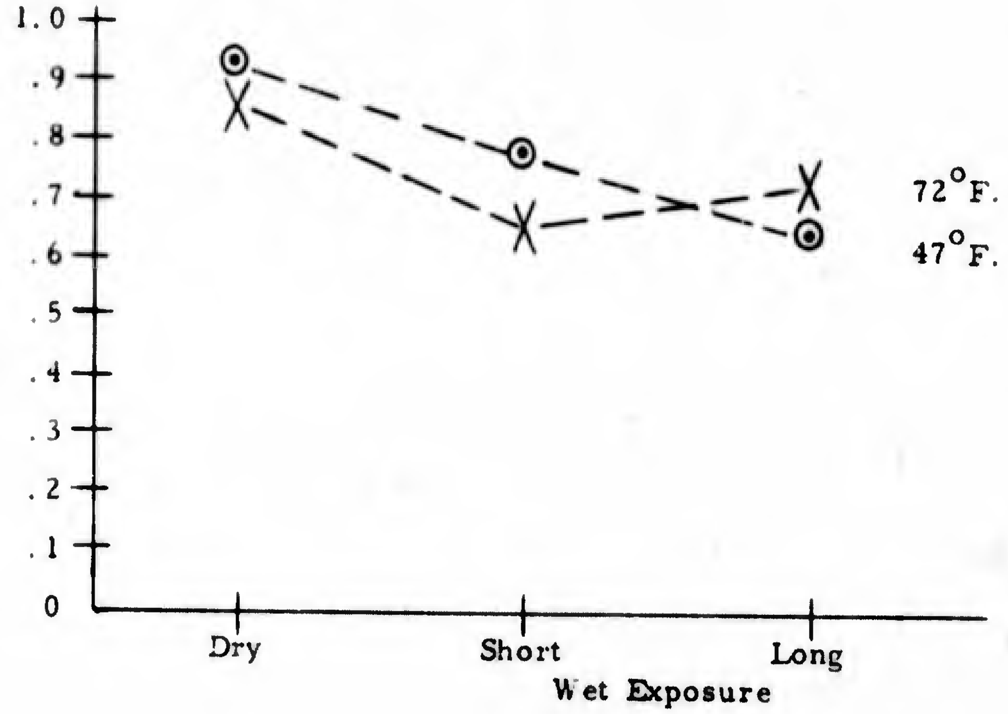
Multi-Task Test

The Multi-Task Test consisted of operating the two-hand tracking device and, at the same time, listening for repeats in the number series which comprised the audio vigilance task. Each trial lasted ten minutes. The average times of exposure to the mid-point of the task were 5, 9, 20, and 24 minutes. The scores were pooled into Short and Long Exposure times, as before.

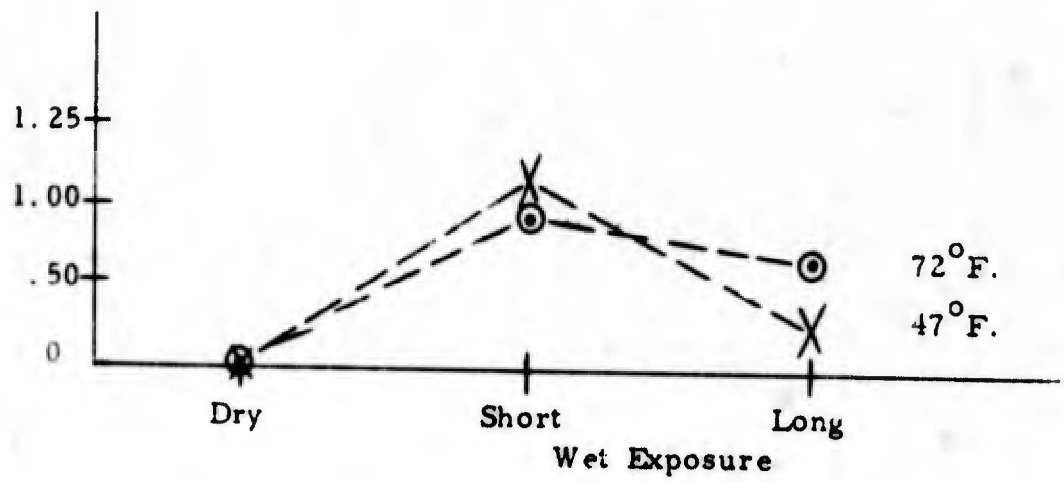
The data from the first set of trials for the two tasks are shown in Figure 16 a, b, c Audio Vigilance and Figure 17 a, b, 2-Hand Tracking. In Figure 16 a, the average probability of detection for the dry trials associated with the 47° F conditions is higher than that for equivalent 72° F dry trials. Thus the wet scores are probably spuriously raised. This effect is very probably due to practice, since the 72° F scores were collected before the 47° scores. A similar effect appears in Figure 17 a where the mean times for performing a tracking run on the two hand tracking device are smaller for 47° F than for 72° F. Again this is attributed to practice.

The audibility of the numbers of the Audio Vigilance Test was impaired in the water due to masking by the noise of the bubbles from the exhaust valve of the breathing regulator. Therefore an observer noted whether exhaust bubbles were present whenever a subject missed a response. When this was the case, the stimulus was not counted. The numbers appearing

(a) Average Probabilities of Detection



(b) Average Frequencies of False Positives Per Trial

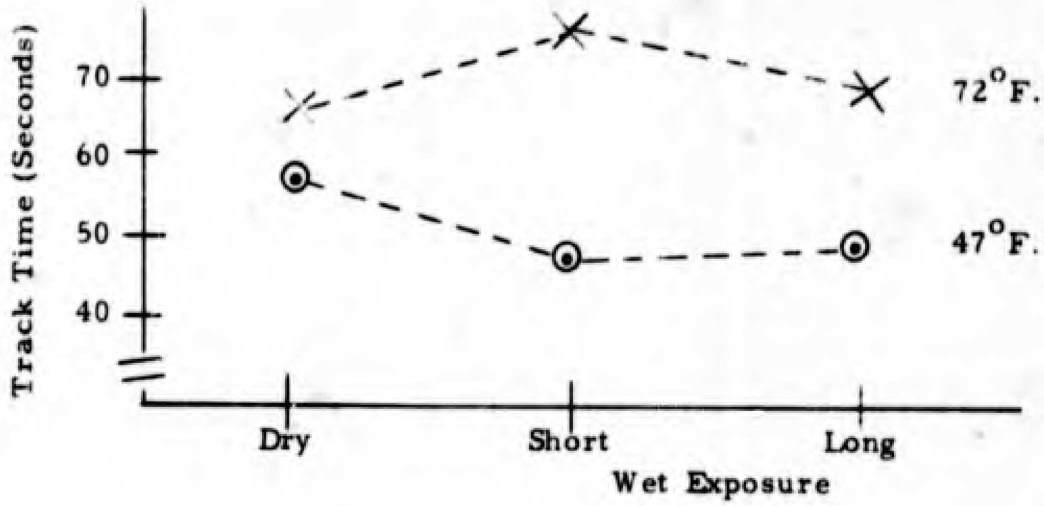


(c) Average Numbers of Possible Detections Per Trial

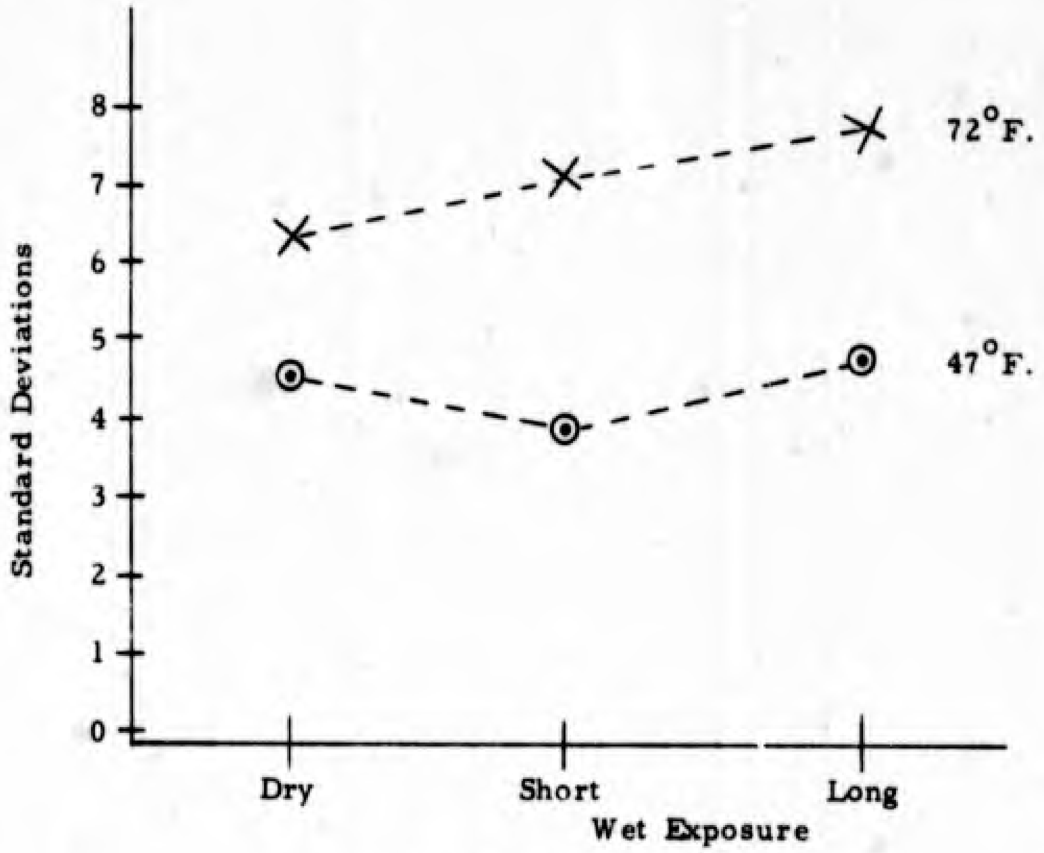
72°F.	17.8	15.3	16.0
47°F.	18.0	15.2	14.3
	Dry	Short	Long

Wet Exposure

Figure 16. Multi-Task: Audio-Vigilance Test--First Trials



(a) Average Times for Track



(b) Average Standard Deviations

Figure 17. Multi-Task: 2-Hand Tracking Test--First Trials

in Figure 16 c give the average number of possible stimuli. The impaired audibility may also have been the cause, or a contributing cause, of the higher incidence of false positive reports for the water conditions.

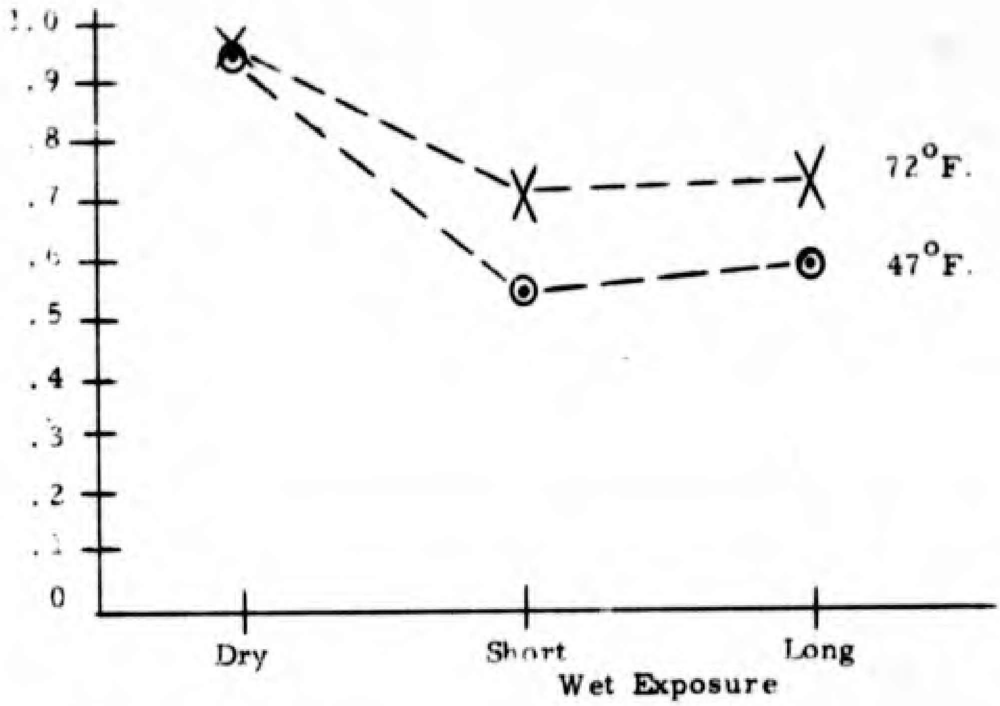
Because the practice effects seemed to be obscuring the consequences of the test conditions, the test was run again in the hope that performance would be more stable. Figure 18 a, b, c and Figure 19 a, b show the data and show that this expectation was realized. In the Audio Vigilance Test, the dry land trials gave essentially the same probability of detection ($p = .95$ and $.96$). For the cold water condition, the probabilities of detection were appreciably lower than for the warm water condition; however there was no effect due to length of exposure. The incidence of false positives was higher than in the warm water condition. This may have been due to the tendency to breathe faster when cold and therefore to produce more masking noise. If this were the case, however, the number of possible detections (i.e., stimuli occurring when subject is not exhaling) should decrease. Such a trend does not occur consistently.

Figure 19 a, b show the second trials for the two hand tracking device. The practice effect has been eliminated, judging from the equivalence of the dry land control scores (31.7 and 32.5 seconds). The cold water condition produces much slower performance and there is an effect of exposure. Performance also becomes more variable in approximate correlation with the slower performance. However the increase in variability is small compared to the increase in the mean scores. It is not a matter of the performance just being much more variable under cold conditions. Rather the performance was much slower while being only slightly more variable.

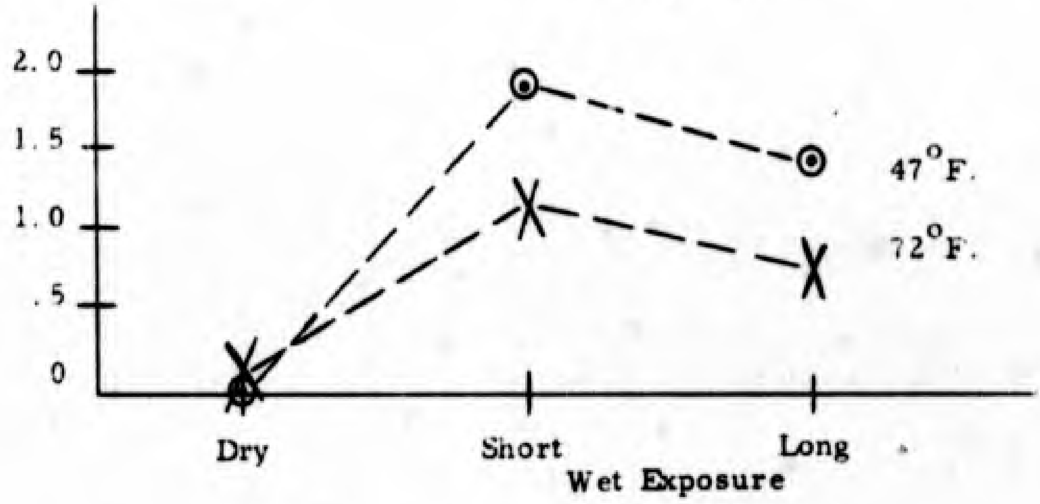
The losses due to cold water in this demanding task were considerable. The subject was only about one-half as good at detecting a transient signal, believed he heard one or two signals per trial that were not present, and slowed down to about half speed in performing a typical manual control task. Overall it appears that this kind of complex multitask is most susceptible to depletion by cold stress.

Subjectively the task was very difficult to do under cold water conditions. Great effort was required to maintain attention to the auditory stimuli and to control one's breathing as best as possible to allow the signals to be heard. As one attended closely to the auditory stimuli, one found oneself slowing down in the tracking task. Progressively one became, so it felt, less flexible in time-sharing attention between the two tasks. One

(a) Average Probabilities of Detection



(b) Average Frequencies of False Positives Per Trial

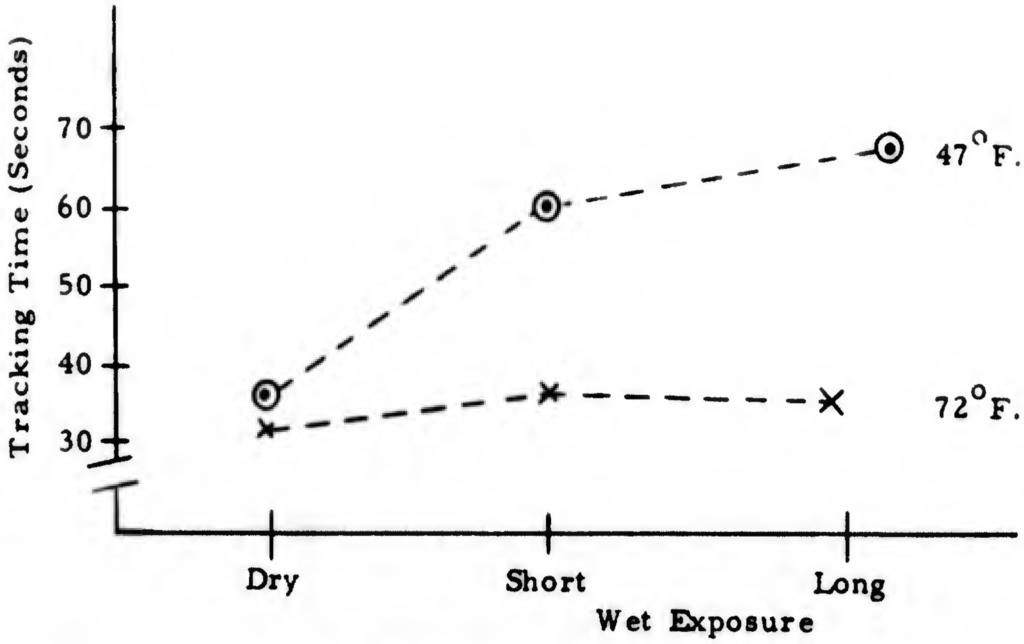


(c) Average Number of Possible Detections Per Trial

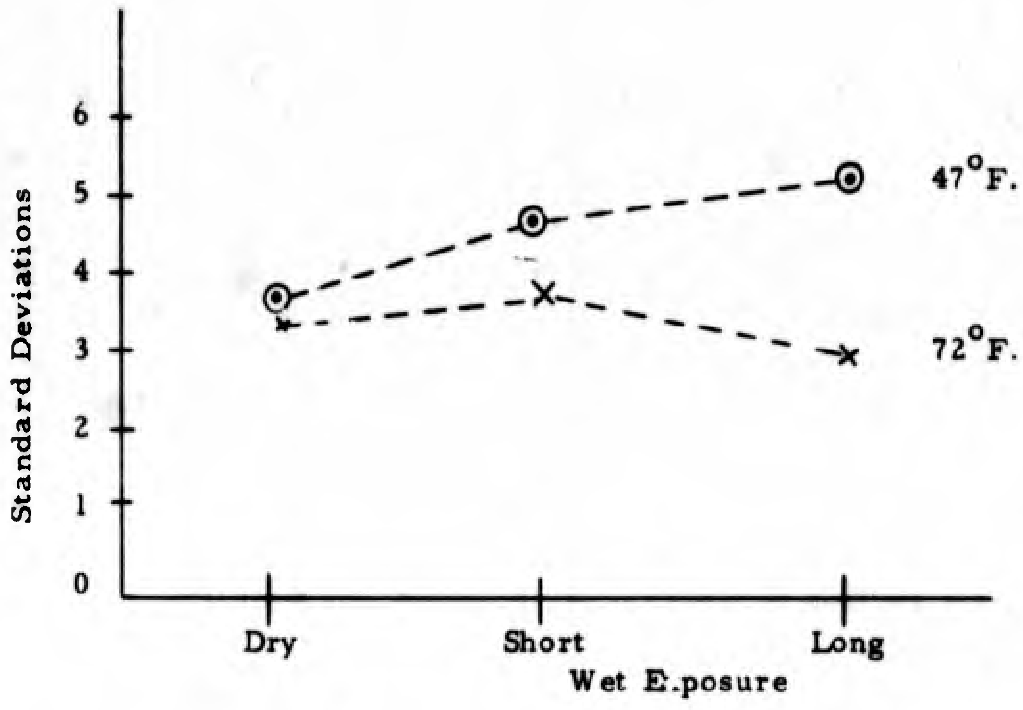
72°F.	18	14.7	15.3
47°F.	18	17.0	12.2
	Dry	Short	Long

Wet Exposure

Figure 18. Multi-Task: Audio-Vigilance Test--Second Trials



(a) Average Times for Track



(b) Average Standard Deviations

Figure 19. Multi-Task: 2-Hand Tracking Test--Second Trials

became conscious to reduced performance, yet however hard one tried, it did not seem to improve matters very much.

Reactions to the "Warm" and "Cold" Conditions

The divers debriefed themselves on a tape recorder and completed scales of "discomfort" and "coldness" after each trial. At 72° F, all the divers felt comfortable and experienced only "slight chilling" or none at all. No diver gave the appearance of discomfort nor felt any urgency about getting out of the tank.

At 47° F all divers experienced stress. At "splash-in", the water did not feel uncomfortable as it seeped into the wet suit; it was more exhilarating than uncomfortable. However exposing the hands at "gloves off" produced definite pain in the hands. Somewhere between 15 and 30 minutes, depending on the person, fairly severe shivering started. One had much less control over the limbs than normal. As the trial progressed, discomfort, pain, and numbness increased. Divers reported feeling "very cold" and experiencing from mild to severe "discomfort" and "pain."

There was no subjective acclimatization to the cold. In fact, the general trend was to feel the water as colder in the later trials. Divers reported that as the trial progressed, they increasingly looked toward its end as an escape from increasingly intolerable conditions. Toward the end of some trials, some divers felt symptoms of depersonalization and reported "mind-wandering" and difficulty in concentrating. On emerging from the water, all divers were shivering, some violently; many times they had difficulty in talking and breathed quickly and shallowly. As noted previously, it took at least one hour to warm up. Some divers reported experiencing minor lapses of memory or concentration for two to three hours after a cold immersion. All divers reported very long sleep hours (i.e., 10 hours or more) during the nights of the period while they were undertaking the cold trials. No diver reported difficulty in sleeping which has been noted elsewhere (personal communication from L. Raymond of the U. S. Naval Medical Research Institute, Bethesda, Maryland).

V. CONCLUSION

The data described in this report is an account of the effect of cold water stress on human performance. It is, clearly, no more than a start toward a definitive account of the behavioral boundaries of divers. Within its limitations, the study has indicated that divers may experience two kinds of impairment to their functions; one due to being in the water and in diving dress, the other due to the cold. The water effect seems to be a hindrance to, mainly, motor activity due to some combination of instability, neutral (approximately) buoyancy, viscous resistance, resistance to limb flexion, and impaired sensory functions. The cold effect has both local (peripheral) and general effects. It causes more or less direct losses in sensory and motor function and it distracts from and disrupts cognitive activity especially when a unit cognitive activity is extended in time so that sustained attention and memory are involved. When a complex behavior is attempted (such as required by the multi-task test) overall impairment is very considerable. It may be supposed, in general, that the more complex and demanding the activity, the greater the losses due to the stress of diving in cold water.

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13. ABSTRACT

This study examines the performance capabilities of divers. Trials were conducted at various water temperatures to assess the effects of cold. Dry land trials provided control performance scores. The capabilities tested were; tactile sensitivity, manual dexterity, manual movement, reasoning (arithmetic), problem solving, memory, and a multi-task capability requiring simultaneous manual tracking and attention to an audio channel. The data indicates that diving in warm water causes loss in motor functions due, it is thought, to the changes and hindrances experienced in the diving condition. Diving in cold water increases the motor loss and causes distraction and disruption in mental tasks; "blocking" in attention and lowered memory capability were found. Impairment of performance on the multi-task was considerable. It is hypothesized that cold water stress, in addition to causing specific sensory and motor losses, causes increasing losses of capability as the task becomes more complex and is more dependent on sustained attention and memory functions.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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