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STUDIES OF DIVERS' PERFORMANCE DURING THE SEALAB II PROJECT

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ABSTRACT

Field studies of divers' performance during the SEALAB II project were undertaken by three teams of 10 men each who lived in and operated from an underwater habitat situated on the bottom at 205 feet. Performance under SEALAB conditions was compared to performance on dry land and to performance in shallow water (15 feet). Tests conducted in the water were: a strength test, an assembly test, a two-hand coordination test, a group assembly test, and a visual test of the detection and recognition ranges of targets of different forms and colors. A test of mental arithmetic was performed inside the habitat. While performance on the mental arithmetic test suffered no deterioration, performance on the psychomotor tasks was less proficient under SEALAB conditions than in shallow water, which, in turn, was less proficient than dry land performance. The data suggests that performance on short-term, simple tasks suffers least impairment, while performance on larger term and more complex tasks suffers more impairment. The decrements in performance are attributed to the various stresses and hindrances of operating in the water rather than to any direct physiological effects (e.g., narcosis) due to pressure or the breathing medium. A conclusion from the vision test was that black targets under the conditions are most visible.

Examination of the qualitative material (written reports and debriefing material) indicates that many of the divers found that tasks proceeded slowly

and that difficulties were encountered. Among other effects, concern for one's own safety may detract from the amount of attention one gives to the task at hand. Various incidents are related wherein divers got into difficulty. While many tasks and activities were undertaken successfully by the SEALAB teams, yet the amount and variety of work that divers can accomplish is limited by the present techniques of diving.

Individual differences among the divers were related to diving performance, and it was found that age and experience had no relation to diving activity. However, the men who indicated that they were least fearful and least aroused by the conditions did the most diving. Also, the men who, in the habitat, were helpful to their mates, gregarious in their social activities, and contacted the outside world least by telephone were most active in their diving.

This report gives an account of the human performance studies carried out during the SEALAB II project. * The total project had multiple purposes and contained a wide variety of studies in nearly every branch of marine science, technology, engineering and medicine, in addition to the studies of human behavior. This report is concerned only to report the measures and observations of human performance taken during SEALAB II. It is a study of men performing various tests and tasks in a water environment, subject to a variety of stresses which, at their worst, endangered life and, at their least, constituted differences from normal existence to which adjustment was required. An understanding of the significance and limitations of these data will be enhanced, however, by some knowledge of the operational procedures and environmental conditions of SEALAB II.

SEALAB II

SEALAB I (O'Neal et al, 1965) had already proved that men could not only survive, but function in an apparently normal manner and suffer no ill effects from living in a submerged habitat for a period of 11 days, at a depth of 193 feet, and breathing an oxygen-helium-nitrogen gas mixture.

SEALAB II was designed to confirm and capitalize on this finding, and to study the total operation of placing and maintaining men in a submerged habitat. A major purpose was to evaluate the diver's capability for doing useful work in the

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open sea, leaving from and returning to the habitat. The primary advantage of using a submerged habitat as a diving base, rather than to conduct diving operations from the surface, is to eliminate the requirement to decompress (i. e., come very slowly to surface pressure). The diver living in the same ambient gas pressure as the water pressure outside (achieved by having an open entryway in the base of the habitat) suffers no compression or decompression penalties upon exiting to the water, provided he remains within a depth band referenced to the depth of the habitat (currently 33 feet above and 66 feet below the depth of the habitat). In such "saturation" dives, the time that each diver can stay in the water is enormously prolonged over the few minutes that are safe for a surface diver to stay at any considerable depth.

SEALAB II is a non-propelled, seagoing craft, much like a small submarine, which can be lowered into the ocean and emplaced on the ocean floor. It serves as an underwater habitat wherein up to ten divers can live for prolonged periods. The living compartment is a cylinder 12 feet in diameter and 57-1/2 feet long. In the submerged state, access is gained through an anti-shark cage suspended below the hull. The diver swims into the cage and ascends a ladder through an access hatch four feet in diameter. He emerges into the entryway. Having removed his equipment and taken a hot shower, the diver enters the main living compartment. This is a long, wide corridor, divided into a laboratory and watch station, galley and bunkroom. Eleven viewing ports are provided in the hull so that the divers can observe the marine scene outside from the comfort of the heated habitat.

The atmosphere in SEALAB contained approximately 85% helium, 11% nitrogen, and 4% oxygen. Replenishment gas was brought in an umbilical from the support ship on the surface or from a partial replacement charge stowed in external bottles strapped to the side of SEALAB. A gas scrubber containing Lithium Hydroxide removed CO_2, while charcoal was used to remove contaminants and odors. Electric dehumidifiers kept down the humidity of the atmosphere; convection heaters and a radiant heating system controlled the space temperature at about 90°F., a comfortable temperature when wearing bathing trunks.

The umbilical between the support vessel and the emplaced SEALAB contained a secondary power cable, a communication cable, an atmospheric gas supply line, a gas sampling line and a compressed air line for power tools. A primary power cable laid underwater from shore provided power to SEALAB; a fresh-water line, also from shore, supplied fresh water. A multiplex communications cable transmitting through a submerged relay station provided a comprehensive capacity for every type of communication between the shore and the SEA LAB.

Of the many special systems used or studied during SEALAB II, the "Hookah" diver breathing system should be noted. Four external lines were supplied from the habitat atmosphere by means of pumps located in the entryway. The diver donned a mask and could swim freely at the end of the line (80 feet) without fear of exhaustion of his gas supply. Normally, divers used the U.S. Navy's MARK VI semiclosed-circuit scuba equipment, which provided an endurance of approximately one hour in the water.

The SEALAB II habitat was put into position on the bottom at 205 feet. It was located about 3,000 feet off the pier of the Scripps Institute of Oceanography, La Jolla, California.

Some of the relevant aspects of the immediate environment of SEALAB II were: the bottom was composed of silt which stirred up into a fog when disturbed by a diver; the water temperature ranged from 47° F., to 56° F., increasing as the study continued; visibility ranged from a few feet to as much as 30 feet and also tended to increase as the study continued; there was an abundance of marine life attracted to the habitat; a species of scorpion fish which became dense on the bottom around the habitat and in the shark cage was capable of inflicting a poisonous sting with its dorsal spines when touched, occasioning considerable pain.

The Human Behavior Study Program

The study was conceived as a joint program involving a physiological program, a social/personality program, and a human performance program. A preliminary report on all of these programs is contained in Anon 1966, details of the social/personality program are provided by Radloff and Helmreich (1966), and Helmreich (1966), from which this report draws in exploring some of the conditions which formed the context for the performance of tests and tasks.

The purposes of the human performance studies were to:

- examine the effects of the environment and the condition of diving on the performance of divers;
- study the work capability of divers operating from a submerged habitat; and
- extract preliminary conclusions on tool and equipment design and the design of task processes with the aim of eventually establishing human engineering specifications of equipment and tasks.

It will become evident that these study goals were only partially attained and that much further work is required to achieve definitive conclusions. This was one of the first attempts at a systematic study of diving operations and the performance of divers. Therefore, it was felt that the opportunity would be used best by setting out to achieve a limited set of specific quantitative data plus acquiring as much circumstantial evidence as was possible in order to characterize the overall response and adaptation of the diver to the conditions. Indeed, this policy was imposed rather than chosen, by the circumstance of the project. There were the typical restrictions on manipulation of variables, control over the course of activities, achieving objective and complete data, etc., which typify field measurement of human performance and which have been discussed recently by Rabideau (1964) and Keenan, et al. (1965). The data gathering operations were a mixture of procedures which, although planned in advance, had to be continually adapted to the exigencies of the unfolding situation.

From a theoretical viewpoint, the study was thought of as an instance of men operating in an unusual and adverse environment. It was hypothesized that the generalized stress of being closer to danger than usual plus the specific stresses in the water of neutral bouyancy, reduced vision and sensory capability in general, lack of communication, cold, high energy expenditure and reduced mobility and motility would lead to some decrement in measured performance. It was further believed, in line with the results of numerous stress studies, that simple, short-term psychomotor tasks would show the least impairment and more complex, long-term tasks the most impairment.

The Studies

Introduction

The literature on the human performance of divers is almost totally concerned with the physiological effects of breathing hyperbaric atmospheres and the effects of pressure and pressure changes. In recent times, a few studies have been directed to measuring various forms of psychomotor and cognitive performance as a function of exposure to various breathing mixtures at various pressures for various time lengths. Kiessling and Maag (1962) report on the temporary impairment of performance on a Modified Purdue Pegboard (7.90% decrement), choice reaction time (20.85% decrement) and a Conceptual Reasoning Test requiring detection of rules of categorization of objects (33 46% decrement) when the decrement was computed between performance at sea level and performance at 100 feet during a 12-minute dive in a pressure chamber. Adolfson (1965a, b), also working in a pressure chamber, reports broadly similar results using a manual dexterity test (nuts and bolts), a mental arithmetic test and a word association test. At the lower depths to which Adolfson exposed his subjects (down to 400 feet), the losses in capability became larger. The observed decrements were attributed to nitrogen narcosis resulting from breathing normal air under hyperbaric conditions. Baddeley (1965) has shown that the decrements reported above are probably the minimal decrements to be expected from divers working in the water. Using a different but similar test to the Purdue Pegboard, he showed that a 6% decrement in a pressure chamber at 100 feet transformed itself into a 49% decrement in the water at 100 feet. The implication is that the relatively slight loss due, it is presumed, to nitrogen narcosis alone is small compared with the loss due to both nitrogen narcosis and the various stresses and hindrances of diving. A possible interpretation of the results is that when diving in the water the reduced capability of the diver due to nitrogen narcosis has larger consequences; that is, there is some interactive effect between the state of nitrogen narcosis and the diving conditions and that the diving conditions alone would not necessarily bring about impaired performance. Alternatively, it may be supposed that diving conditions do induce impaired performance which causes an additive decremental effect over that due to nitrogen narcosis. Some support of the latter interpretation is found in a report by Baddeley and Flemming (1965). Eight divers were studied breathing air and an oxygen/helium mixture at 200 feet. Currently it is hypothesized that breathing an oxygen/helium mixture at 200 feet produces no narcotic effects (the evidence from both SEALAB I and SEALAB II supports this conclusion). However, Baddeley and Flemming found, for instance, that on a manual dexterity test divers at 200 feet breathing an oxygen/helium mixture suffered a 32% decrement, while divers on air had a 47% decrement. In both cases the decrement was with reference to performance at ten feet. These results indicate that the effects of diving at depth alone brought about a 32% decrement. But this conclusion must be tempered by the further observation by Baddeley and Flemming that performance on a mental addition test suffered 20% and 15% decrements on air and oxygen/helium respectively. One needs to hypothesize either that the oxygen/helium did bring about some narcosis or that the diving conditions occasioned the loss in mental addition capability.

It was intended that the SEALAB II experiments would illuminate these issues and, in particular, indicate the type and amount of behavior loss due to diving conditions other than narcosis.

The Tests

The tests were planned to sample basic features of man's psychomotor behavior. In designing the tests, it had to be recognized that the test instruments would be immersed in water and subject to rough handling, that only a short time would be available for each test run, that the tests had to be self-administered by the divers, and that the environmental conditions would be adverse and changeable. Therefore, the test apparatus and test procedures were made as simple as possible. The tests range from requiring simple, short-term behavior to relatively complex, prolonged behavior. The focal skills required in the four tests were: application of maximum force, manipulative dexterity, eye-hand coordination, and cooperative assembly of components.

The Strength Test

The strength test consisted of two torque wrenches mounted on the shark cage of the SEALAB II structure. The handle of one wrench was horizontal; the other, vertical. The "lift" test, carried out using the horizontal handle, consisted of bracing one's feet on a platform and lifting upwards on the handle, which was positioned about 30" above the platform. The "pull" test was carried out with the vertical handle. It consisted of grasping the handle with the left hand at about shoulder height and grasping a grip with the right hand. By having the position of the right-hand grip adjustable, each man could achieve a full arm-stretch position. In both tests, the subjects were told to exert maximum force. The forces achieved were recorded by a deflection arm which moved a recording marker along a scale. The ft.-lbs. applied were then read directly from the number opposite the recording marker.

These strength tests were chosen because they are representative of the actions required when divers are used as primary power sources and because they provide data applicable to the design of hand tools. In addition it was expected that the forces recorded in the lift test would be about 2 to 3 times as large as those recorded in the pull test, thus giving an appreciable range in terms of muscle activity.

The Triangle Test

The triangle test consisted of assembling three one-foot lengths into a triangle by joining the ends of the lengths together with nuts, washers and bolts. The subjects were required to assemble each corner by placing a washer on each side of the two lengths, a bolt through these four pieces and securing the whole by affixing a nut on the end of the bolt to finger-tightness. The test was given in four forms. Bolt sizes were either 5/32" or 5/8" (referred to as "small" and "large"). The holes at the ends of the lengths were placed either symmetrically, so that any end of a length would fit to any end of the other two lengths; or asymmetrically, so that an end of one length would fit only to one end of one of the other two lengths (referred to as "same corners" or "different corners"). While it was possible to assemble the "different corners" version of the test with any combination of lengths, the one, and only one, correct manner of assembly resulted in the exact superimposition of two lengths at each corner. Thus, the four versions of the test (small, same corners; large, same corners; small, different corners; large, different corners) varied the challenge to the subject in terms of the fineness of fingertip dexterity required and the degree of perceptual-cognitive involvement.

The test was selected as being representative of tasks requiring the assembly, adjustment and general handling of small items of equipment.

Performance of the test in the water was expected to deteriorate when compared to dry-land conditions, as a function of lowered efficiency of the musculature, particularly the hands (e. g., due to cold, wearing gloves, etc.); of decreased visibility and of problems in maintaining body orientation with respect to the work components.

The Two-Hand Coordination Test

The two-hand coordination test required the diver to move a peg along a track by means of turning two knobs which controlled the position of the peg in X, Y coordinates. The test required the continuous visual monitoring of the position of the peg with respect to the track and the coordination of rotary movements between the two hands. The test was selected as being representative of tasks which require continuous control or adjustment of equipment, dynamic systems, or vehicles.

The mechanism box was placed on a stand four feet high. On two sides of the mechanisim box were two knobs, 2" in diameter. Turning the right-hand knob caused a peg to move in the X coordinate, which was a maximum distance of 9"; turning the left-hand knob caused the peg to move in the Y coordinate, which was a maximum distance of 12". The peg stood up 1" above the top of the box. One of nine templates could be placed on the top of the mechanism box. In each template, a track was cut; at the start of each test, the peg was positioned at one end of the track (Y coordinate). The subject then had to move the peg along the track to the other end as quickly as possible.

The characteristics of the tracks cut in the nine templates prepared for this test were as follows:

<u>Group 1-Orthogonal Lines</u>

Plate #1 A square S

Plate #2 Same as #1 except for a "bump"

Plate #3 Same as #2 except for two "bumps"

<u>Group 2-Sloping Lines</u>

Plate #4 A straight line S

Plate #5 Same as #4 except for a "bump"

Plate #6 Same as #4 except for two "bumps"

<u>Group 3-Curved Lines</u>

Plate #7 A curved line S

Plate #8 Same as #7 except for a "bump"

Plate #9 Same as #7 except for two "bumps"

Tracks in Group 1 required the subject to move the peg only in either the X direction or the Y direction for any one portion of the track. Tracks in Group 2 required him to set up a constant ratio between X and Y movements for any one portion of the track. Tracks in Group 3 required the subject to adjust the ratio of X and Y movements constantly, all along the track. Within each group, the first track conformed to an S-shape, the second track had one perturbation in it, and the third track had two perturbations in it. These perturbations in the tracks required the subject to make a number of quickly succeeding changes in his control of the peg.

Group Assembly Test

The group assembly test required four subjects to cooperate in assembling a structure, portrayed to the subjects by a perspective drawing, from lengths of pipe and appropriate connectors. Eighty-four separate pieces had to be used. The purpose of this test was to represent the type of light-duty structure that divers have to manipulate and to study the effects of the diving situation on cooperative action.

Form/Color Test

In addition to the four psychomotor tests, one test of sensory function was conducted successfully in the water.* The form/color test measured the detection of form and color underwater. Four targets were used: a white square, a black circle, a white cross, and a yellow triangle. Each target measured 30

*Tests of tactile sensitivity, visual acuity, auditory acuity, and sound localization were attempted; these tests failed due to inappropriate or malfunctioning equipment.

centimeters across its maximum dimension. They stood in a line separated by 3 feet between centers and 4 feet above the bottom. The divers swam toward the targets along a tape and noted the distances at which they could detect the targets and identify positively the forms.

Mental Arithmetic Test

This test was performed inside the habitat and was scheduled for the 2nd, 7th and 14th days of the 15 day submersion period. Each test item consisted of multiplying a two-digit number by a one-digit number; zero's, five's, and multiples of eleven were excluded. The subject was instructed to complete as many items as possible in a two-minute period.

Procedures

Training, and Collection of Base Line Data

On two occasions prior to the submersion of SEALAB II, the divers were available for instruction, practice, and the gathering of baseline data on the psychomotor tests and the mental arithmetic test. Due to the pressures of the program, the amount of practice accomplished varied considerably from diver to diver. However, all 28 divers received written instructions on test procedures; 26 divers received some practice on the psychomotor tests; 27 divers completed at least two trials on the mental arithmetic test. The divers were also instructed in the method of reporting their performance on a "Sortie Report Form". This form contained appropriate checklists and open-completion parts so that the diver could report on his diving equipment, the activities undertaken, the environmental conditions, and his subjective response to the diving sortie. It was scheduled to be completed for every sortie undertaken from the habitat.

During the practice period, as much "dry-land" base line data on the psychomotor tests were taken as was possible. The actual data take was:

Strength Test:	14 subjects; one recorded measurement each on "Lift" and "Pull" after practice.
Triangle Test:	12 subjects accomplished at least one recorded measurement on each of the four versions of the test after practice; 2 subjects provided incomplete data.
Two Hand Coordination Test:	27 subjects performed at least one trial on Plate No. 5 after practice; also each of the 27 subjects had trials on 4 of the other 8 plates.
Group Assembly Test:	6 teams of four subjects performed the test once each.

A limited opportunity was afforded to gather data on a shallow water dive in a fresh water lake. The tests were undertaken at 15 feet depth, in water that was exceptionally clear (approximately 100 feet visibility) and at 70° F. The data take was:

Strength Test:	No data.
Triangle Test:	12 subjects accomplished at least one recorded measurement on each of the four versions of the test.
Two Hand Coordination Test:	14 subjects accomplished at least one recorded measurement on Plate No. 5. Also, each of these 14 subjects had trials on 2 of the other 8 plates.
Group Assembly Test:	2 teams of four subjects performed the test once each.

SEALAB Procedures

Three teams of ten men each followed one another in occupying SEALAB II for 15 days for each team. One man remained from Team I to continue with Team II, and another member of Team I made up the complement of Team III.

While the psychomotor and other tests were scheduled within the general schedule of diving, it quickly became apparent to all concerned that the tests would have to be fitted in as and when they could. There existed also the problem of motivation in the sense that the teams faced a multiplicity of tasks, and were reluctant to devote any considerable time to the human performance tests at the expense of other and, often, operationally more urgent tasks. It would be tiresome to the reader to recount all the difficulties, makeshift solutions, and impromptu scheduling that occurred. Suffice it to say that in retrospect, the pre-planning was hopelessly optimistic but the gathering of the test data that was achieved was, under the conditions, a credit to all concerned.

It turned out that each diver did perform one or more of the tests, and it was noted whether the performance was done at the start of the sortie (i.e., within five minutes or so after leaving the habitat) or at the end of the sortie. The data returned each day on the "Sortie Report Forms" was put onto punch cards for later statistical reduction. After each team completed its fifteen-day stay, each team member was debriefed within 3 days by means of a questionnaire and an interview.

Results and Analysis of Tests

The Strength Test

Table 1 gives the mean measurements and standard deviations on the strength test of all the data that were collected. Where a diver did more than one trial, his data was first averaged.

	Stretch			Lift		
	No. of Subjects	Mean	S. D.	No. of Subjects	Mean	S. D.
Dry Land	14 (11)	238 (238)	27.4	14 (12)	614 (628)	103.5
Sea Lab	22 (11)	187 (200.1)	42.3	23 (11)	557 (600)	104.5
% Diff.		21% (16%)			9% (5%)	

Table 1. Strength Test: data given in ft-lbs. The number of subjects, means and % difference given in parentheses are for divers who did the test both on dry land and under Sea Lab conditions.

A more direct way of estimating the loss of effective strength by going from Dry Land to SEALAB conditions is to restrict the data to those divers who did the test both on dry land and under SEALAB conditions. These data are given in parentheses in Table 1. It can be seen that the differences between taking all the data and only the data from matched observations is relatively slight.

The data were inspected for any differences between doing the test at the beginning versus the end of the sortie; no differences were found. Also, the data showed no trends across the 15 day period of each team's stay.

The results indicate that a diver suffers only a slight loss in the maximum force he can apply to a torque arm. The greater loss found for the stretch condition may be attributed in part to the neutral buoyancy condition. When the diver pulled between the two hand grips in the water, he was lifted off his feet and his body weight did not exert much influence on the recorded pull as it would do on land. Otherwise, the drop may be attributed, conservatively, to possibie stiffening of the torque wrench mechanism, to some difficulty in achieving good hand-grip and, possibly, an impatience to get the test over with and be about one's business or return to the habitat. To the extent that the decrement existed, therefore, it is reasonable to attribute it to the conditions under which the measurement was taken rather than to an intrinsic loss of muscular energy.

The Triangle Test

Figure 1 records the mean values obtained on the triangle test taking into account all the observations that were made. Eleven subjects performed the test on dry land and in shallow water; it can be seen there is very little difference between the total group and the paired measurement group. The data taken under SEALAB conditions was sparse; however, the data shows a consistent pattern which increases its credibility as to being representative of the performance levels to be expected under SEALAB conditions.

The average percentage increase in time taken to assemble the triangle with respect to dry land conditions was for shallow conditions 21% and for SEALAB conditions 49%. The data also indicate that the four versions of the test do not become equally more lengthy to perform as a function of the depth condition. It can be seen (Figure 1) that performance on the simple version of the test (Triangle Number 1) and on the hardest version of the test (Triangle Number 4) worsens more than performance on the intermediate versions of the test. The data permits the hypotheses that it is difficult to perform even simple tasks expeditiously compared to somewhat more demanding tasks (due, perhaps, to decreased motility) and that difficult tasks become disproportionately more difficult. The hypotheses deserves more definitive testing in future studies.

In interpreting the data, several conditions of performance need to be recognized. While for the dry-land and shallow water conditions, all subjects

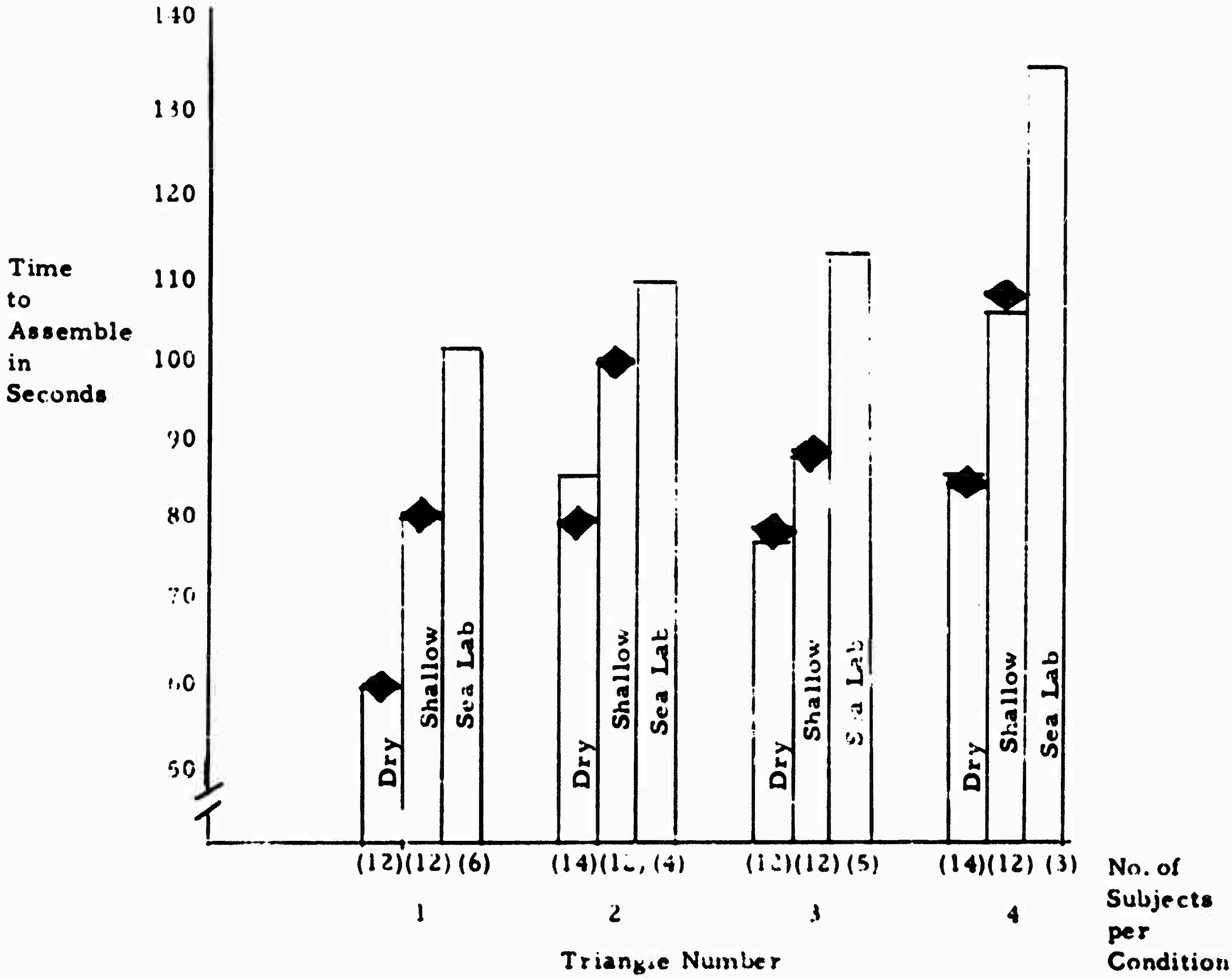

Figure 1. **Triangle Test: Mean times to assemble triangles for Dry Land, Shallow Water, and Sea Lab conditions. Triangle No. 1, Large Bolts, Same Corners; No. 2, Small Bolts, Same Corners; No. 3, Large Bolts, Different Corners; No. 4, Small Bolts, Different Corners. Number of subjects providing data for each mean given in parentheses; the symbol indicates mean performance of the eleven subjects who performed the test for both Dry Land and Shallow Water conditions.**

performed barehanded, all subjects under the SEALAB conditions wore some form of glove on both hands except for one diver who wore only one glove. The gloves ranged from thin skin-tight gloves, used to protect against cuts and abrasions rather than to provide thermal insulation, to 3-finger 3/8" diving gloves. The data does not indicate any systematic relationship between type of glove and speed of test; perhaps there is a trade-off between cold hands versus encumbered hands. Visibility was, of course, much poorer under the SEALAB conditions, which would tend to make the "different corners" version of the test more lengthy to do. Partly due to the low visibility condition, some divers performed the test floating upside down so that their face masks were close to the surface on which they had the bag containing the triangle parts. Add the possibility of a scorpion fish or two floating across the scene, and the picture of the SEALAB test conditions begins to be realized. Evidently the test results do not indicate necessarily the inherent loss, if any, of manipulative skill but rather the difficulty of exercising whatever skill one may have under the operational conditions of diving.

It is interesting to note that the decrement in performance between shallow and SEALAB diving conditions for the triangle test was 23%, which compares with the 32% found by Baddeley and Flemming for a comparable test performed under comparable conditions which has been cited above. This degree of agreement is encouraging to the belief that the performance capability of divers can be measured and predicted with some consistency.

The Two-Hand Coordination Test

Unfortunately, the data gathered on this test from the trials run under SEALAB conditions is unreliable. The machine suffered from corrosion; the timing equipment (a cable running from switches on the machine to a stop-clock in the habitat) malfunctioned, and the runs were timed on wrist watches; and the times actually reported are a mixture of times taken for a single run along a track and a two-way run (out and back) along the track. Discounting the widely deviant data and the data taken when the machine was stiff to operate due to corrosion, it is estimated that Plate No. 5 took about 150 seconds (average of 4 divers) which compares with averages of 125.8 seconds and 144.3 seconds for dry land and shallow conditions respectively (see Figure 2). The SEALAB data estimate is reported because, while the measurement was probably not very accurate, it is reflective of the reports of the divers concerning their difficulties in manipulating the controls and seeing the pin in the track clearly enough (at times) to obtain good eye-hand coordination.

The data for the dry-land and the shallow condition is shown in Figure 2. The data shows consistent trends in that in shallow water the time to complete the runs on any one of the tracks is lengthened, there is also the suggestion that the difference in performance time between tracks of different difficulty also increases, i. e., the differences between tracks 2 and 3, 8 and 9 (but not 5 and 6) for the two conditions.

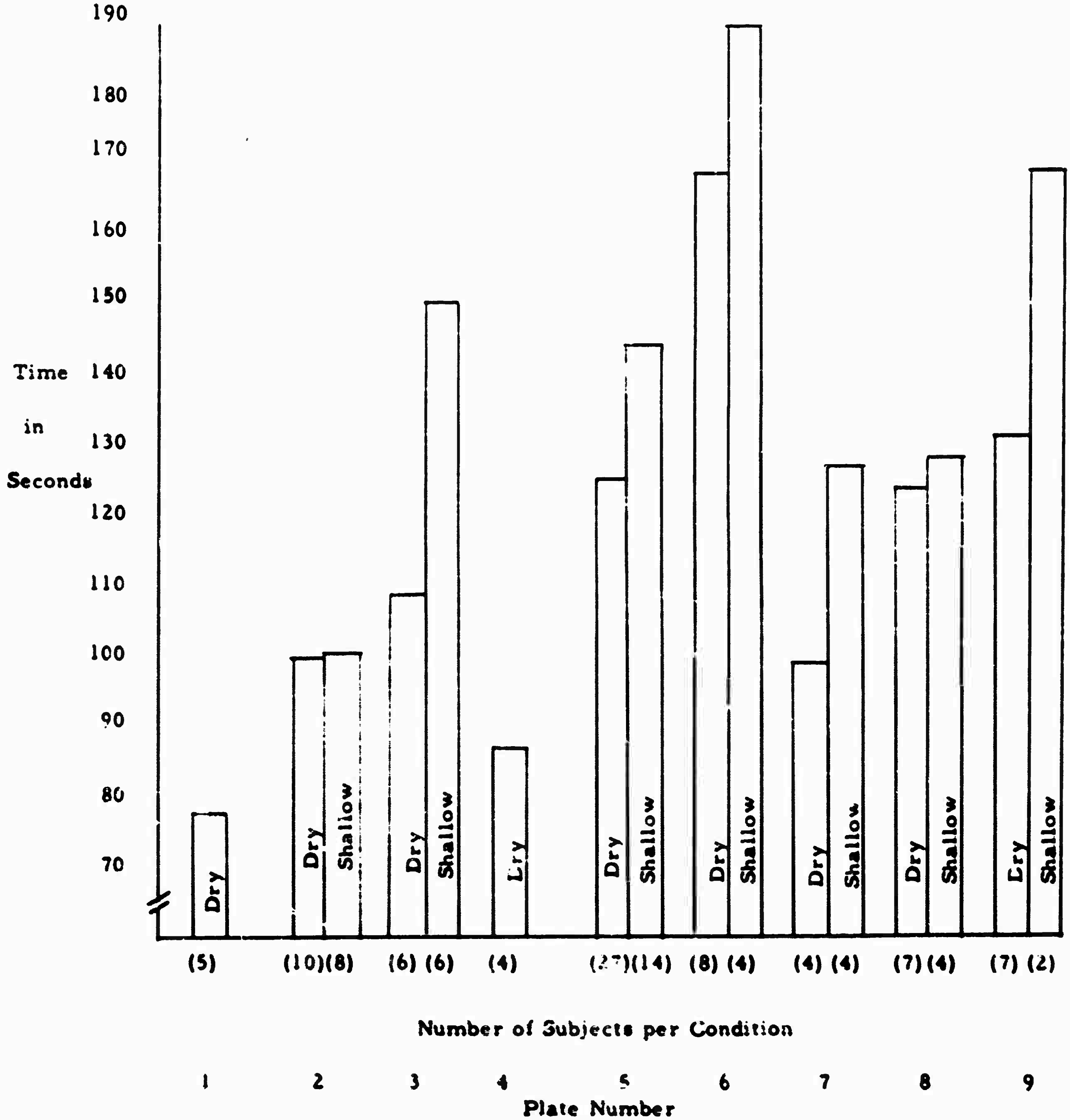

Figure 2. Two Hand Coordination Test: Mean times of performance for Dry Land and Shallow Water conditions for each of the nine test plates. Number of subjects providing data for each mean given in parentheses.

The Group Assembly Test

Only one trial of the group assembly test was conducted during the SEALAB submersion. The time taken for assembly was 12 minutes and 20 seconds. The circumstances of doing the test were that for about one hour before exiting from the SEALAB, the four men concerned practiced building the structure and deciding precisely how to do it. Each man had also assembled the structure before on dry land or in shallow water. Under these circumstances, it seems most appropriate to select for comparison the best times achieved under shallow water and dry land conditions; these were 8 minutes 10 seconds and 6 minutes even respectively. The other time for shallow water conditions was 22 minutes, and for dry land trials the times ranged from 6 minutes to 40 minutes and not completed. The difficulty was that without some practice at assembly, the team could become very confused in how to achieve correct assembly and the divers had only very limited time to devote to the human performance test program. The SEALAB team reported only one or two abortive moves during their assembly, and it seems fair to conclude that their degree of preparation was ideal for the task. The major difficulty facing the underwater teams was the lack of verbal communication. Other difficulties were low visibility and the lack of control over body motions which caused a lot of bumping and movement between the divers clustering around the work item. Indeed, the SEALAB team reported that their task would have taken much longer if they were not working on the platform attached to the shark cage and thus had something to hang onto.

Form/Color Test

Six divers were used to obtain a total of 20 observations on each of four targets. Table 2 shows the mean detection and recognition distances.

It is apparent that the black disc is both detected and identified at greater distances than either of the white or yellow targets. This is particularly interesting when considering that it is the smallest of the four targets in area. (Black disc = 707 sq. cm., white targets = 900 sq. cm.)

Mental Arithmetic

The mental arithmetic test was conducted at the beginning, in the middle, and at the end of each team's stay. The results were inspected first to see whether there was any trend across time; there was none so the data was pooled. Complete data was collected on 27 of the divers. Table 3 summarizes the results.

	Targets			
	Black Circle	White Square	Yellow Triangle	White Cross
Detection	24.4	18.3	16.7	16.5
Recognition	20.0	14.2	13.5	13.4

Table 2. Mean Detection and Recognition Distances in feet for the Form/Color Study: 6 subjects providing 20 observations.

	Dry Land	Sea Lab
Mean No. Attempted	25.84	29.67
Std. Dev. of No. Attempted	7.53	9.07
Mean No. Correct	23.76	27.20
Std. Dev. of No. Correct	7.43	8.69
Mean Ratio of Correct/Attempted	9.12	9.12
Std. Dev. of Ratio of Correct/Attempted	.07	.07

Table 3. Mental Arithmetic Test, Dry Land and Sea Lab Data: mean scores for 27 subjects.

It is evident that the divers in SEALAB suffered no impairment of ability to perform this test. In fact, they performed, on the average, more multiplications with the same ratio of corrects as they had done on dry land.

We now turn to other forms of data which are descriptive of the work capability of the divers in SEALAB II.

Number and Length of Sorties

The average number of sorties undertaken per day and the average duration of the sorties for the three teams broken into succeeding five-day periods for each team are shown in Table 4.

It is evident that, as time went on, there was a cumulative facilitating effect which enabled more time to be spent in diving. Much of this can be attributed to an increased familiarization on everyone's part with the equipment and operations.

During the sorties a large variety of tasks and activities were accomplished in addition to the tests previously described. The fact of their accomplishment was an adequate demonstration of the operational capability of divers for these tasks. Unfortunately we know very little more than that certain tasks were done. These tasks included setting up instruments and equipment on the bottom or around SEALAB: carrying out marine life sur-

Team	Succeeding Five-Day Periods 1st 5 days N	T	2nd 5 days N	T	3rd 5 days N	T	Combined N	T
1	1.04	38.56	.98	41.00	1.12	42.82	1.05	40.79
2	1.38	35.16	1.22	42.24	1.53	54.30	1.38	43.90
3	1.90	61.44	1.78	64.86	1.40	60.97	1.69	62.42

Table 4. Number of sorties and diving time per team (10 divers) and for succeeding five-day periods where N is the average number of sorties per day per diver and T is the average length of sortie in minutes.

veys using appropriate equipment; carrying out simulated salvage of an aircraft hull by blowing in foam to provide positive buoyancy; using a stud gun on a steel sheet; exploring the bottom and gathering samples of biological or geological significance; taking movie and still pictures; etc.

Some Individual Differences*

Overall level of activity in the water is indicated by the number of sorties undertaken, average duration of sortie and number of tests undertaken. When using these indications as criterion measures of differences in involvement of different individuals with diving activities, it is necessary to recognize that the expectation initially was that all divers would participate in diving activities equally. Injury, medical condition, equipment function and malfunction, scheduling by team leader, were among the determinants which caused variation in diving activity. However, there also appeared to observers to be factors of individual differences in motivation toward diving which contributed to the range of diving activity.

Age and Experience

The correlation of the diving activity indications with age and diving experience of the divers showed that no association existed. (Table 5.)

*The data reported here was collected and analyzed by Dr. R. Radloff of Naval Medical Research Institute and Mr. R. Helmreich of Yale University. An extended treatment of this and other data appears in Helmreich 1966 and Radloff and Helmreich 1966.

	Age	Experience
No. of sorties	+ .09	+ .27
Diving time	- .04	+ .01
No. of tests performed	.00	- .21

Table 5. Correlations (r 's) of the 28 divers' age and experience with diving activity.

The range of age and experience was considerable. Mean age was 35.14 years with a standard deviation of 5.52; mean experience was 10.96 years with a standard deviation of 5.84. Apparently men at all levels of age and experience could undertake the amount of diving activity required or, alternatively, what they were motivated to undertake. A preliminary conclusion would be that given a group of men with varied background it is not important, within limits, how old or how experienced any single individual is in determining the contribution he will make.

Fear and Arousal

A self-administered mood checklist completed every two days included 13 items indicative of the degree of fear (anxiety, apprehension) and 8 items indicative of the degree of arousal (reactivity to the conditions). The responses, on a 3-point scale, were summed over the 15 days and correlated with the diving activity indications.

It is clear from Table 6 that diving time and number of sorties are highly correlated and can be regarded as providing one indication of in-water activity. This indication is negatively correlated with fear and arousal suggesting that the divers who dived the most were those who felt least fear of the conditions and who were least aroused from their normal condition by being in the SEALAB situation.

	Fear	Arousal	No. of Tests	Diving Time
Fear	--	--	--	--
Arousal	+ .56**	--	--	--
No. of Tests	- .25	- .14	--	--
Diving Time	- .50**	- .52*	+ .22	--
No. of Sorties	- .44*	- .47*	+ .09	+ .89**

*$p < .05$
**$p < .01$

Table 6. Correlations (r's) between indicated "fear" and "arousal" with diving activity.

Helpfulness

A measure of "helpfulness" was generated by direct observation (by a closed TV system) of the divers performing chores in the habitat, particularly meal preparation and clean-up chores. The correlation between this measure and the number of tests performed in the water is +.64 ($p < .01$).

Gregariousness

A measure of "gregariousness" was generated by direct observation (by a closed TV system) of the ratio of time spent by each diver in the company of other divers in the habitat. The correlation of this measure with diving time is +.50 ($p < .01$) and with number of sorties is +.46 ($p < .01$).

External Contact

The number of external telephone calls (i. e., calls other than communications within the SEALAB project communication system) was documented for each diver: communication content was not monitored. The number of external telephone calls correlated with diving time -.50 ($p < .01$) and number of sorties -.49 ($p < .01$). The inference may be drawn that the men who most excluded the outside worlds from their minds, or at least did not feel the need to contact it very much, were the ones who were most active in undertaking diving sorties.

These various indications start to define the type of men (low fear and arousal, helpful and gregarious and not needful of external contact) who will be enthusiastic about getting out into the water and performing tasks there. The preliminary definition of these desirable traits will serve as a basis for the development of future selection programs.

Debriefing Data

The debriefing data is rich in material which "paints a picture" of what it is to like to live under the sea in close company with 9 other men and to contend with the manifold difficulties of doing jobs under difficult conditions. The following samples are selected from the debriefing material on the basis that the information is directly relevant to human performance.

Clothing and Cold

The protective "wet-suits" that the divers used, left much to be desired. Only three of the divers reported that they were really satisfied with their suits. While a very considerable effort was made to equip the divers with adequate wet suits, it seems that much more attention will have to be given to this feature in the future. Without departing from the current concept of a wet suit, it would appear most desirable to have zippers that don't jam or break, and for the suits to fit well enough so that there would be only a small flow of cold water into the suit or that the suit should not raise painful welts at flexion points.

The reported experience of the divers with respect to the cold was very varied. Some said they were never cold; some said they were always cold. Some said that they grew used to the cold; others said that the only thing that changed was that their wet suits, after initial compression (due to the pressure), expanded and regained their thermal properties. Some said it was warmer diving at night, however there were no recorded changes in nighttime water temperatures over daytime temperatures. There was, further, no evidence that the realtively slight changes in temperature that did occur affected measurable performance (i. e., on the psychomotor performance tests). Undoubtedly, however, it was cold and some divers did become very cold. One diver characterized the effect on him of the cold as making him become impatient and more ready to cut corners or leave jobs incompleted or not attempted, in order to get back to the warmth of the habitat. It is very evident that better suits and/or heated suits are required for effective operation in the lower temperature ranges.

Gloves

Nearly everyone used gloves. The majority dove with gloves whatever their task because as a diver put it "it's better to be clumsy and slow with gloves than to run the risk of your hands becoming useless through the cold."

However two divers said that they never wore gloves. One of these men was a photographer. He said his hands almost never became so cold that he could not work his cameras and that, provided his hands were only moderately cold, he could use his equipment better than with gloves on.

Tool Using

The divers consistently reported that they had no trouble using tools such as wrenches, screwdrivers, hammers and various special tools. However, the real meaning of these comments seem to be that they encountered no unusual difficulties over the normal difficulties of using tools underwater. There are several kinds of difficulties in using tools; they are due to one's (approximate) neutral buoyancy, the viscosity of the water and to the problems of transporting and keeping track of tools.

The neutral buoyancy and viscous resistance problem is evident when attempting to use a large hammer. Virtually all the impact energy must come from the hammer falling through the water. One cannot swing a hammer or aim it effectively along a trajectory. Applying torque to tools is similarly difficult; without some structure against which to brace oneself one cannot be very effective.

The problem of tool management is also a considerable one. Because the free-swimming diver (more generally two divers swimming as "buddies") operates as an isolated entity, he must carry or attach to his person the supplies that he will need at the worksite. Beside the limitation that this restriction imposes in terms of the kind and quantity of tools and materials that can be brought at any one time to a work site, there is the difficulty of actually undertaking the transportation. Carrying tools in the hand, strapped to the wrist or in a bag, encumber the diver and slow him down and can cause him to become entangled. Once at the work site, there is the problem of keeping track of the tools. It is apparently very easy to mislay tools in the mud and murk which are characteristic of many bottoms on which divers work. Thus, on one sortie from SEALAB, a diver mislaid a hacksaw and an 8-lb. hammer. Various other tools and items of equipment were lost or mislaid and found again only after considerable search or by chance. The problem of maintaining vigilance over tools and putting them down at some location where they can be found again takes time and effort, sometimes much time and effort.

Dive Management

The difficulties of tool management and the errors that occur may reflect a more general difficulty of maintaining currency with a developing situation. One diver discussing the general topic of conducting a diving sortie said about his difficulties ".....you pre-plan a dive and you're not able to adjust very well to a situation. Your mind is set. You've got to do something a certain way. You just don't adjust to it as well as you wish you could." The tenor of the remarks of many of the divers in the debriefing interviews echoed this feeling that when one's plans were disturbed, it was difficult to adapt effectively to the new situation. Another diver put the proposition in a different way: he said "a good diver is a good planner." The implication of this remark, taken with the rest of the evidence, is to indicate that it is very difficult to cope with a situation unless one has prepared a plan of action. This phenomenon may be interpreted as a reflection of the manifold stesses that divers are subject to.

Diver Concerns

A major theme running through nearly all the debriefing interviews is a preoccupation with yourself, your location, your equipment and wondering whether everything is going right. The following quote from one diver would reflect the thoughts expressed by many. "So much of your mental capacity is devoted to listening to your exhaust, wondering whether it's working right, keeping in mind how far you are from the laboratory and taking care of your tools. You're spread pretty thin and you don't have much of your mental capacity to devote to the performance of your task."

While it would give a false impression to suggest that the divers were ineffective or that they did not, in fact, accomplish many tasks which some reported as "going very easily," "no problems," etc., generally the accomplishments were with respect to simple short-term tasks which had been thoroughly practiced. The other side of the story is exemplified by this feeling of despair which was written on a daily report form after the diver had been down for 6 days. "Today we completed only one out of 2 simple jobs. I don't understand it at all, but it presently seems to be a fact......I have been doing some stupid things, and other people feel the same way. We are trying to be ultra-careful with the MK6's (breathing apparatus), but things still happen such as flooded cannisters, and two cases of people going out with their gas off. Once outside, it seems immensely slow--it takes much time to do even simple jobs. We really need about 2 weeks to just get used to this kind of work; again, I don't understand why."

Incidents

There were several incidents of a more or less critical nature. The incidents that occurred may be categorized broadly as:

1. Deprivation or contamination of gas supply
2. Sudden change in buoyancy
3. Entanglement

While there were also occurrences of divers becoming temporarily disoriented as to their whereabouts, none of these developed into an actual state of being lost.

The records indicate that there were at least six occasions when divers suffered a deprivation of gas supply, and there was one occasion when a diver attributed a coughing fit and great difficulty in breathing to baralyme contamination from the CO_2 scrubbing cannister. On all occasions, the action taken was to return to the habitat entrance way. For one diver, at least, the race between the onset of unconsciousness and the gaining of the entrance way through the obstacles of the shark-cage door and the profusion of wires and cables was touch and go. It is noticeable that no attempt was made to use the buddy breathing technique which was possible when swimming with a companion using the Mark VI equipment. The implication would appear to be that a companion diver does not constitute a sufficiently immediate safety capability under the circumstances of diving that obtained.

One diver experienced a sudden positive buoyancy due to the inflation of one side of his chest bag brought about by a free-flowing bypass valve. He was in danger of floating to the surface which would have meant certain death.

"We were in the process of putting---(a stake in). I made a quick turn to assist (his companion diver) and my bypass started free flowing. Well, before I knew it, I would estimate I was from 15 to 20 feet off the bottom. My bypass was free flowing and one side of my vest bag popped up--came loose; and I feel part of it was my fault. I really needed (more) practice on the Mark VI before making the dive down there and I got a little shook; in fact, I got damn shook. I was swimming to the bottom as hard as I could and I wasn't making any headway for a while. All this time I was trying to get the bag down. I was trying to reach my bypass which I was able to do and I was pushing on the rod trying to get the free flow to stop. What I should have done was open up my pop-off valve, pulled on it and emptied my bag. But I didn't think about it... Anyway, I didn't, so finally I decided, well, the most important thing for me to do is to get to the bottom and I got to the bottom and got to that stake we were driving in and held on." With the help of two other divers, the diver returned to the habitat with some difficulty.

In studying the protagonists' accounts of the incident, certain inferences can be drawn. It is clearly dangerous to use diving equipment that can suddenly change its buoyancy when engaged in a saturation dive. If the possibility of the contingency cannot be eliminated entirely, adequate training and preparation should be mandatory. The lack of a means of swimmer-to-swimmer communication meant that the buddy diver did not know that serious danger threatened his companion until after the worst danger had passed (of popping to the surface). A third diver who came on the scene (breathing from a Hookah hose) failed to comprehend the situation very well and in attempting to help the diver back to the habitat hindered, rather than helped.

This critical incident has been reported in some detail so that the reader may become aware of some of the actualities of diving and the dangers that threaten While, in fact, this incident ended happily, due, no doubt, to the degree of skill and experience that the divers possessed, yet it was an intimate brush with catastrophe. The incident suggests the room for improvement that exists for human factors specialists, joining with the diving fraternity, to apply themselves to.

While there were many reports of temporary entanglement, only one report indicated that divers were in any immediate danger. One form of "nuisance" entanglement is becoming entangled with equipment one is carrying. As soon as the diver is burdened, as sometimes he must be, with various objects, some of which are tied to him by lines, there always exists the likelihood that the lines and the equipment will become snarled around him.

A diver described a potentially dangerous incident of entanglement as follows: .....(I had no especial difficulty) with the (Hookah) line but, boy, there are a lot of lines down there that I got tangled up in, both with the Hookah and the Mark VI. One thing that really scared me--one time when (a diver) and I were out--we got a buoyant pot. We snapped this pot on (to the line from the surface) and it started to go up. (The other diver's) Hookah line was hooked up on this thing and it started up, caught him, and he started going up with it. I was right after him, and it turned out my line was tangled up in it too."

They managed to disengage themselves aided by the prompt action of the man on watch in the habitat who saw the occurrence and instructed surface control to slacken the up-haul.

The diver who was speaking before continued: "There are so many lines down there at the entrance of that thing. I was out swimming with the Mark VI and I got it tangled up in the breathing part and it cut off. Just one of these lines going out here and there and I didn't even see it. Of course, your field of vision is not too great anyway, and you can easily swim into things like that. It actually cut off my air for a minute and it scared me until I reached around and figured out what it was. My buddy came over and untangled me. I think that is a real problem of safety; all those lines out there."

Discussion

Perhaps the most significant attribute of the data is the absence of any decrement in measured mental function inside the habitat (the mental arithmetic test), combined with the measured decrement of performance in the water. There is no reason to believe that going into the water from the habitat should have incurred any degradation of mental functioning. The gas mixture that the divers breathed in the water was essentially the same gas mixture, under the same pressure conditions(within one atmosphere up and two atmospheres down of pressure which, it is thought, is quite an insufficient change to bring on narcosis) as breathed in the habitat.

The attrition of performance and the feelings of, at least some, divers that accomplishment fell short of expectation must be attributed to the difficulties and impediments of operating in the water.

While the data collected are hardly conclusive, the general pattern of the results suggests that simple, short-term tasks, which can be conducted according to a simple plan (e. g., the strength test and certain of the tasks undertaken in the simulated salvage operations), suffer very little impairment as compared with dry-land conditions. However, as soon as the task becomes more complex, a progressive impairment of proficiency sets in; the trends in the triangle test data are indicative of this interaction between task complexity and environmental stress. Insofar as the one test run on the group assembly test may be indicative of performance on a group-participative task, relatively gross amounts of impairment appear.

There is also an unseen part of the data, namely, that which would describe what the divers did not do. Compared to dry land, the diver is enormously limited in his range of behaviors. He is virtually confined to visual observation and the manipulation of relatively simple objects within some quite limited area (in the case of SEALAB II, a maximum distance of about 350 feet from the habitat). His work effectiveness is limited by the short length of time he can stay at a work site, by his own slow motion and by his necessary preoccupation with contingency conditions that might affect his safety. He is characteristically cold and has limited vision; his suit makes him clumsy and his neutral or slightly negative buoyancy complicates the performance of tasks. The tools he uses are limited in type; for tasks requiring more sophisticated equipment, he is still dependent on surface support.

The impression was gained that the amount of work accomplished and the comparatively good showing on the psychomotor performance tests were due to the combination of very high morale, the agressive achievement-oriented motivation, and the high expertise and long experience of most of the divers.

It would seem that if future operations are to become more effective, wider in range and more institutionalized, a great deal less reliance will have to be put on the diver *per se*. There is a need to develop many features of diving equipment so that various man/equipment combinations can face the underwater environment and underwater tasks without the present reliance on diver courage and skill which, high though they may be, are often relatively inadequate resources for the tasks at hand.

Considering the more specific results of the study, there is no evidence to suggest that divers cannot perform a full range of manipulative tasks or use all of the conventional hand tools. Their performance will be slowed as much by the problems of personal mobility, equipment transportation, and the like, as by deterioration in speed of work at the worksite. The diver's strength is not seriously impaired, but his value as a primary power source is limited by the problem of applying force in a buoyant medium. Torque-free power tools would be a boon to divers, provided the problems of getting the power to the worksite (e.g., by cables) are not too considerable.

The data analyzing the personal and social attributes of the divers who achieved good work records in the water suggests that divers should be of a relatively phlegmatic disposition and able to contend with stress and danger without being preoccupied with them. They should be motivated to help out and ready to take on whatever duties must be performed. Persons who tend to be good mixers will also be the ones tending to achieve more in terms of diving operations; and persons who can lose their concerns about the outside world and accept their isolation will tend to be the ones who will be motivated to engage fully in the diving operation. These findings of divers' traits which, at least in the case of SEALAB II, disposed them to be effective performers in the water, form a basis for the development of future selection procedures.

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13. ABSTRACT

Field studies of the three 10 men teams of divers participating in the SEALAB II project were undertaken. During each team's 15 day submergence at 205 feet, psychomotor tests and a vision test were conducted in the water, and a mental arithmetic test in the habitat. Compared to base line performance (dry-land and shallow water conditions), performance on the mental arithmetic test showed no deterioration while performance on the psychomotor tests showed considerable deterioration.

Many divers found that their in-water activities proceeded slowly; among other causes of a more physical nature, concern for one's safety may detract from the amount of attention one gives to the task at hand.

The most active divers in the SEALAB group were those who indicated that they were least fearful and least aroused by the conditions and who were helpful, gregarious, and made least telephone contact with the outside world.

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