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Diver temperature and performance changes during long-duration, cold water exposure

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Vaughan, W. S., Jr. Diver temperature and performance changes during long-duration, cold water exposure. 1975. Undersea Biomed. Res. 2(2):75-88.–Twelve Navy divers participated in 4- and 6-hour open-water test trials of a 2-man wet submersible in 6°C water. Skin and rectal temperatures of the crews were continuously recorded and performance measures were taken in three task areas: pilot tasks, sonar-operator tasks, and crew-coordination tasks. Results suggest a complex, task-dependent effect of cold stress from deep body cooling. Rectal temperature change was relatively insensitive to differences in exposure conditions, however, and is probably a poor index of cold stress for use as a correlate of performance degradation between normal and clinically critical values of deep body temperature.

cold
telemetry
performance
vehicle
rewarming

Short-duration exposure to cold water limits the diver's performance effectiveness as a consequence of peripheral cooling; long-duration exposure is presumed to further limit performance effectiveness due to deep body cooling. Peripheral cooling is known to reduce effectiveness in tasks which involve touch sensitivity, grip strength, and finger or manual dexterity; deep body cooling is presumed to degrade higher-order perceptual and cognitive functions. Research evidence concerning the effects of peripheral cooling is abundant and permits quantitative specification of both functional relationships between temperature and performance and limits to effective levels of performance. Mills' (1956) review of various indices of tactile sensitivity, for example, reveals an L-shaped functional relationship with finger-skin temperature between 33°C and 0°C with the *break* in the sensitivity curve at approximately 8°C. Clarke, Hellon, and Lind (1958) present a U-shaped functional relationship between grip strength and temperature of the brachioradialis muscle of the forearm. At a muscle temperature of approximately 27°C, grip strength is optimal and degrades as the muscle becomes either colder or warmer. Various researchers have studied the effects of hand cooling on dexterity tasks (Gaydos 1958; Gaydos and Dusek 1958; Clark 1961; Lockhart 1966 and 1968) with results indicating a range of hand-skin temperatures between 10° and 15°C as the critical temperature at which criterion levels of dexterity performance begin to degrade.

There are no comparable research results relating systematic reductions in deep body cooling to impairments in higher-order task performance. The study of performance in long-duration cold water exposures is a relatively recent activity and has been proceeding with caution, exposure conditions gradually becoming longer and colder. The field has been further slowed by a relative lack of instrumentation for measuring both deep body temperature and task performance under water. Many diver performance-oriented researchers have bypassed body-temperature measurement, relating performance levels directly to the exposure temperature.

Bowen (1968) studied scuba divers exposed to a range of water temperatures to a limit of 8.3°C for intervals less than 30 min. Deep body cooling was measured by comparing pre- and postexposure urine temperatures and the differences were on the order of 0.3°C. A variety of tasks were studied and performance of many was poorer in the water than in air but few were affected by differences in water temperature; an exception was a two-hand coordination task. Stang and Weiner (1970) lengthened the exposure interval to 90 min in 10°C water and took pre- and postimmersion readings from an oral thermometer. Average change was 2.2°C and the authors acknowledged the unsuitability of this measure as an estimate of deep body cooling since the divers were cooling oral tissues by breathing cold air. Most of the tasks required by the test divers were dexterity-assembly type tasks except for a two-choice reaction-time task and performance of this task was significantly degraded by the cold water exposure. Beagles and Coil (1966) tested effectiveness of various wet suits by placing divers in 0°C water to the limit of their willingness to stay submerged; one female diver stayed 3 hours while rectal and various skin temperatures were being recorded. No tasks were performed by these divers, however. Egstrom, Weltman, Baddeley, Cuccaro, and Willis (1972) exposed divers to two water temperatures, 25.5° and 4.5°C for 45 min and recorded performance in a vigilance monitoring task. Deep body temperature was not measured and performance in the two water temperatures was not significantly different, 77% vs. 71%. Vaughan and Mavor (1972) studied diver performance in controlling the depth of a wet submersible over 4-hour exposures to 16.5°C water. They measured water temperature and diver skin and rectal temperature continuously via waterproofed instrumentation. Hourly standard deviation of depth was used as a measure of performance in this compensatory tracking task and no significant change in vehicle depth-holding performance occurred over the 4-hour exposure interval. Average decline in pilot rectal temperature from the first to the fourth hour was 0.7°C; depth-control performance was not different either from hour-to-hour or from criterion levels of performance established during training.

One explanation for the lack of consistent performance deterioration in tasks of greater complexity than assembly-dexterity is that the test divers have not been made sufficiently cold; another is that the types of tasks required of test divers in cold water studies have not been sufficiently demanding in terms of task load or the involvement of the perceptual-cognitive processes. The purpose of the present study was to explore further the hypothesis of performance decrement as a function of deep body cooling by extending both the severity of the exposure conditions and the types of tasks required of test divers in the context of wet submersible operations.

METHOD

A cold water test series was conducted at the Naval Torpedo Station, Keyport, Washington, using a manned, wet submersible. The test vehicle was a 2-man, battery-powered, free-flooding submersible with a tandem seating arrangement: pilot in the forward compartment and sonarman aft. A reliable, hardwire communication system linked the two crewmen. Six 4-hour and four 6-hour continuously submerged test runs were made in the Port Orchard Channel of Puget Sound. Water depth was approximately 100 fsw, vehicle running depth was 15 fsw, and water temperature at operating depth varied between 5.8° and 6.3°C with a mean of 6.0°C. The test scenario was based on a vehicle-oriented mission profile involving developmental equipment and procedural concepts. The cold water tests were preceded by a 3-month training period during which six two-man crews were practiced in the tasks and habituated to long-duration submerged operations in warmer (14°C) water. Both hardwire and telemetry instrumentation for recording diver physiological response and task performance were used during each cold water test trial.

PILOT TASKS

The primary task of the submersible's pilot was the simultaneous control of depth and heading at prescribed values, essentially a two-variable compensatory tracking task. Vehicle translations were controlled by a joystick; fore-aft movements controlled pitch-depth, and lateral movements controlled yaw-heading. Heading and depth feedback came from a compass repeater display and a round-dial depth gauge. Continuous records of both heading and depth were included in the vehicle-performance instrumentation package and the standard deviations of observed measures were used as indices of pilot performance over time.

SONAR-OPERATOR TASKS

Two equipment systems were operated by the sonarman. The first was a passive sonar receiver connected to an externally mounted hydrophone which could be manually rotated through 360°. A pointer attached to the swivel arm indicated on an etched plate the relative bearing of any sound source localized by the sonarman. The second was an active sonar transceiver which activated a remotely located transponder and digitally displayed range information to the sonarman. This equipment had two range scales and a selector switch which the sonarman used appropriately as the vehicle either opened or closed range with the transponder.

In the mission phase of the test trials, the sonarman's main task was to simultaneously monitor bearing to a sound source via the passive system and range to the source via the active system. Range-bearing combinations were recorded on a preformatted Plexiglas form at eight prescribed times during the conduct of this phase. Ranges recorded by the sonarman could be scored for accuracy against the record obtained by the hardwire data system. Bearings recorded by the sonarman could be checked only roughly against an idealized geometric model of the vehicle's expected position relative to the sound source through time.

CREW-COORDINATION TASKS

Pilot and sonarman coordinated their activities via hardwire communication link to accomplish two tasks. The first was an acoustic homing task wherein the sonarman used the passive sonar system information to orient the pilot to the bearing of the target relative to the vehicle's heading. As the pilot adjusted heading according to the sonarman's instructions, the bearing of the target gradually shifted to 000°, or directly ahead. As range closed, the target signal was acquired on the pilot's display and the final phase of target intercept was accomplished by the pilot. The second coordinated task was required during the mission phase of the test trials. The pilot monitored heading and time, while the sonarman monitored range and bearing to a reference beacon. A series of reciprocal legs of a maneuver pattern were run by the pilot controlling the shoreward turns on the basis of time-on-leg and the sonarman controlling the seaward turns on the basis of bearing to the reference beacon.

INSTRUMENTATION

Two instrumentation systems were developed to provide data records of crew performance and temperature. The principal system was a hardwire package designed around a 13-channel oscillograph recorder. This system included sensors for water temperature, time, two skin temperatures, two rectal temperatures, vehicle heading, depth, and range to a transponder. Signal-processing circuitry and recorder were packaged in a water-tight container with through-fitting receptacles for sensor input and carried aboard the vehicle. Table 1 summarizes the capabilities of this system.

TABLE 1

Hardwire instrumentation system characteristics

Channel	Function	Calibration range	Recording unit
0	Time	0-8 hr	15 sec
1	Sonarman thigh temperature	20-35°C	0.1°C
2	Sonarman rectal temperature	33.5-38.5°C	0.025°C
3	Pilot rectal temperature	33.5-38.5°C	0.025°C
4	Pilot thigh temperature	20-35°C	0.1°C
5	Water temperature	2-10°C	0.05°C
6	Compass heading	360°	2°
7	Vehicle depth	0-50 fsw	0.5 fsw
8	Range to transponder	0-1000 yd	10 yd

The hardwire system was self-contained; therefore data records were inaccessible while the submersible was in the water. As a safety measure, an acoustic telemetry system was used for real-time monitoring of core temperature and heart rate while the divers were in the water. An acoustic telemetry system for ECG had been developed by Slater, Bellet, and Kilpatrick (1969) and later a temperature capability had been added (Slater and Bellett

1969). These equipments were modified and their capabilities extended for use in submerged vehicle operations. As modified, this system was capable of sensing, transmitting, and recording core temperature from both divers and the ECG of the pilot. Prior to each test dive, subjects swallowed miniature endoradiosonde pills which transmitted core temperature from within the digestive tract. Small antennas were worn in the divers' weight belts to receive radio signals from the pill transmitter and carry them to the signal processor-transmitter secured to the vehicle's hull. The signals were electronically processed in the transmitter for sequential acoustic transmission through the water to a receiving hydrophone lowered from a safety boat. Hydrophone signals were then passed on to the telemetry receiver, which decoded the signals and printed them on a standard single-channel, strip-chart recorder.

TEST-DIVER CHARACTERISTICS

Twelve men of Underwater Demolition Team Eleven, Naval Special Warfare Group, Pacific, were the test divers. Prior to the cold water tests, they were given approximately 20 hours of training in the test-scenario performance requirements. Training was conducted over a 3-month period in San Diego Bay in water temperature approximately 14°C and included 4-hour trials.

Test divers wore tailored "Farmer John" wet suits and breathed compressed air from open-circuit scuba on all runs. The wet suit consisted of a 1/4-inch overall, a 1/8-inch vest with hood, and a 1/4-inch jacket with hood. The suits were individually tailored, zipperless, nitrogen-blown neoprene rubber with the rubber side of all pieces worn toward the diver's skin to minimize heat conduction. Boots and mittens of 3/16-inch neoprene were worn.

External insulation was standardized by controlling wet-suit characteristics. Internal insulation (subcutaneous fat percentage) was determined for the purpose of relating differences in temperature change to differences among the test divers on this variable. Keatinge (1969) has reviewed the laboratory evidence of the importance of body fat in retarding heat loss and Damon and Goldman (1964) have determined the most empirically valid formulas for estimating body-fat percentage from skinfold measurements. Harpenden Skinfold Calipers, manufactured by British Indicators, Inc., were used to measure each diver's skinfold thickness. Four or five measurements were taken from both preferred sites, subscapular and triceps, and means of the set of measures were used to describe each diver's skinfold thickness. Following Damon and Goldman (1964), Pascale's formulas for converting skinfold thickness to density and Grande's formula for converting density to body-fat percentage were applied to the triceps and subscapular means[1]. Table 2 presents the test divers' physical characteristics in detail. Body-fat percentage entries in the table are averages of the calculations based on triceps and subscapular skinfold measures.

Examination of Table 2 reveals the homogeneity of the divers regarding body fat. The subjects ranged narrowly between 12.3% and 15.3% on this variable and, consequently, differences in temperature change were not likely to be accounted for by inter-diver differences in body fat. Essentially, both internal and external insulation were standardized in these cold water tests.

[1] Density = 1.0896 − .0179 cm (subscapular skinfold)
Density = 1.0923 − .0202 cm (triceps skinfold)
Body Fat Percentage = 4.0439/Density − 3.6266.

TABLE 2

Descriptive characteristics of the test divers

Test divers	Age	Height (in)	Weight (lb)	Body fat (%)
1	34	72	190	15.30
2	20	70	170	14.20
3	21	68	160	14.20
4	21	69	167	13.20
5	22	68	147	13.25
6	22	69	157	13.70
7	24	73	170	12.30
8	20	75	190	13.45
9	29	69	165	13.45
10	20	68	154	13.05
11	21	72	180	14.00
12	20	65	140	14.95

TEST PROCEDURE

Test procedures were organized into three phases: predive, dive, and postdive. Predive procedures included a medical check and interview, diver instrumentation, and task briefing. Diver instrumentation included the taking of skinfold measurements, ingesting the endoradiosonde pill, having the thermistor attached to the medial thigh, and inserting the rectal probe. The task briefing was given orally and required details were written on Plexiglas slates. The pilot was given a series of headings to hold for specified time intervals at a prescribed depth. The sonar operator was given these same instructions and, in addition, a formatted recording form and grease pencil for recording ranges and bearings with reference to acoustic beacons. The instrumented, dressed, and briefed divers then entered the submersible at pierside, where they plugged their instrumentation leads into the hardwire and telemetry data systems via underwater connectors.

The dive phase included a transit out, mission-area maneuvers, return transit, and rendezvous. During the transit phases the pilot held a series of headings for specified time intervals. In the mission area, crew-coordinated maneuvers were accomplished while the sonar operator recorded ranges and bearings to a reference beacon. Crew-coordinated acoustic homing tasks were required at the terminus of both transit phases. The difference between the 4-hour and 6-hour test scenarios was a lengthening of the transit phases. Throughout the dive phase, telemetry data were recorded at 15-min intervals and plots of both divers' core temperatures and pilot heart rate were continuously updated aboard the safety boat.

Postdive procedures were initiated when the vehicle surfaced at the end of either 240 min or 360 min of submerged operations. Upon surfacing the vehicle crew was helped out of their several plug-in harnesses and gotten into a rubber boat by safety divers. The test divers were then transported to a pierside rewarming facility, a large 2-man tank filled with water at 40-41°C as recommended by Keatinge (1969). The wet-suited test divers were in the hot water bath within 7 min of their exit from the submersible. Core temperatures were recorded at 10-min intervals by means of the telemetry equipment while the divers rewarmed in the hot water bath. During the rewarm phase, test divers were interviewed regarding their subjective response to the long-duration cold exposure.

RESULTS

SKIN TEMPERATURE CHANGES

Skin temperature was recorded continuously from the medial thigh, the record was sampled every minute, and hourly means were computed from the 60 measurements. The medial thigh was chosen as the recording site since temperature readings at this site have been shown to approximate mean skin temperature from 7 sites (O'Hanlon and Horvath 1970) and from 10 sites (Teichner 1958). Since data recording was initiated when the divers were in the water, no in-air baseline measures can be reported. The initial measurement was 1 min into the dive phase of the test scenario. Figure 1 describes hourly changes in skin

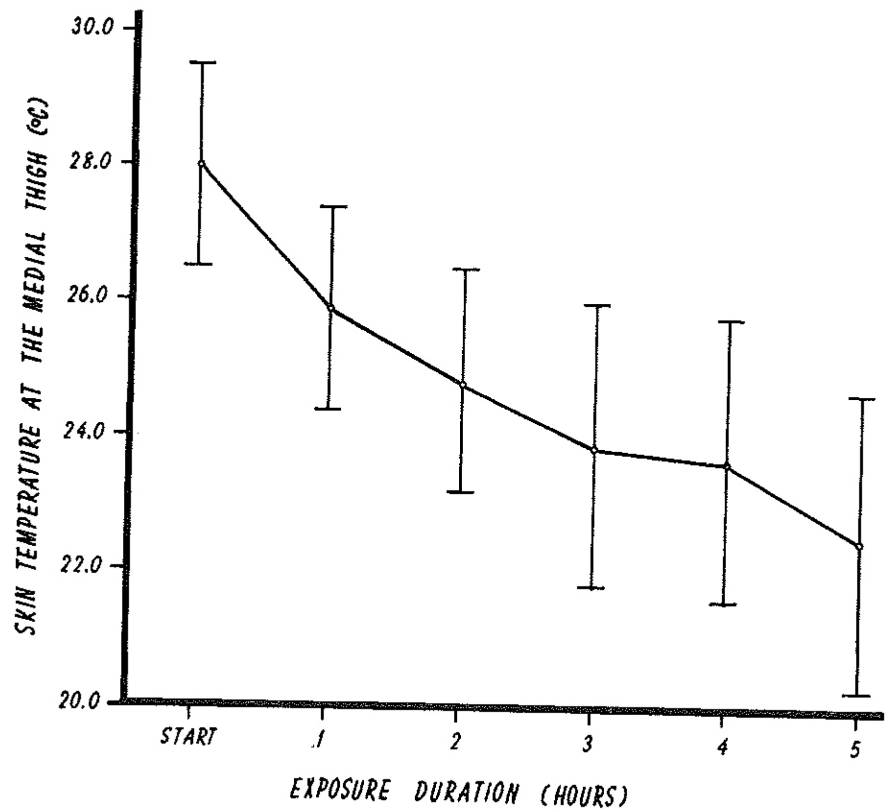

Fig. 1. Skin temperature as a function of exposure hour in 6°C water (means and SDs, n = 11)

temperature as a correlate of exposure to 6°C water. Data for the sixth hour are missing due to equipment failure and a minimum calibration of the sensor to 20°C; several readings in the sixth hour were outside the calibrated range. Data points are means of 11 individual means for hours 1-4 and of 6 individual means for hour 5. Mean skin temperature declines progressively from 28.0°C to 22.5°C, approximating a linear function of exposure time.

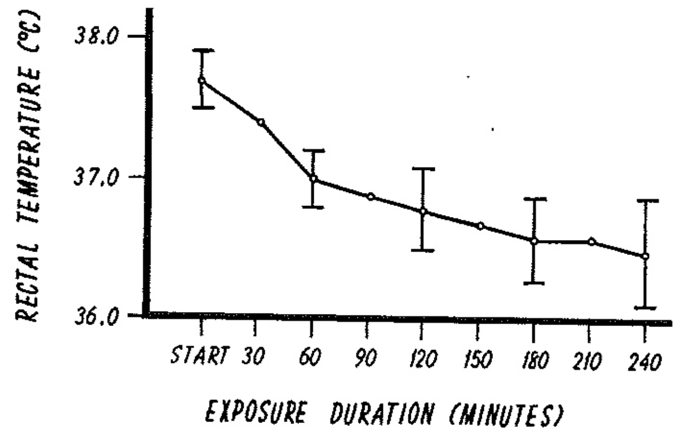

Fig. 2. Rectal temperature at 30-minute intervals during a 4-hour exposure to 6°C water (means and SDs, $n = 10$)

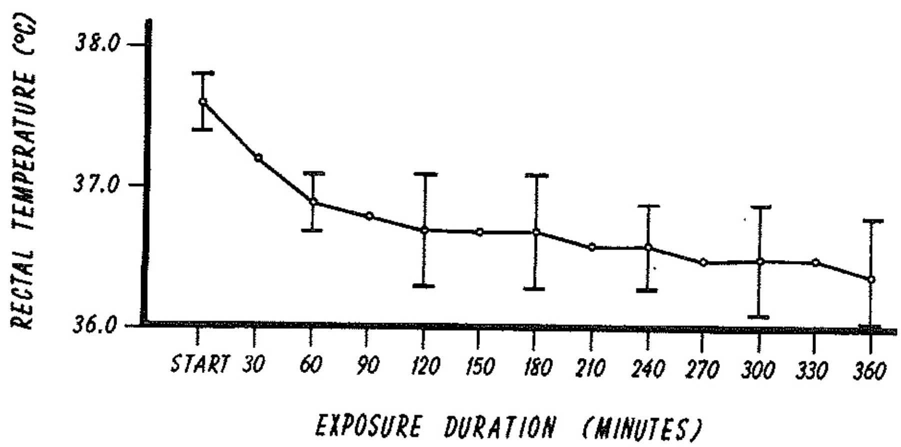

Fig. 3. Rectal temperature at 30-minute intervals during a 6-hour exposure to 6°C water (means and SDs, $n = 6$)

RECTAL TEMPERATURE CHANGES

Rectal temperature data were obtained from 10 test divers during 4-hour exposures and from 6 test divers during 6-hour exposures to 6°C water. The continuous data record was sampled at 30-min intervals and means and standard deviations of these individual values are shown in Figs. 2 and 3. The figures show rectal temperature gradually falling to an asymptote at about the end of the second hour of exposure. The 4- and 6-hour functions are similar in general form, and in initial and final mean values. Average initial temperature was 37.7°C in the 4-hour trials and 37.6°C in the 6-hour trials; final mean values were 36.5° and 36.4°C, respectively. In both 4- and 6-hour trials, mean change in rectal temperature was 1.2°C. Rectal temperature for these samples of divers appears to have stabilized at a mean value of approximately 36.5°C and to have remained at that level to the limit of the exposure, 360 min. Also apparent in the figures was the wide range of individual differences in rectal temperature in spite of the homogeneity of the divers with respect to body-fat percentage and wet-suit characteristics. Individual differences in rectal temperature change ranged from 0.6° to 2.1°C during the 4-hour exposures and from 0.9° to 1.6°C during the 6-hour exposures.

RECTAL vs. INTESTINAL TEMPERATURES

Test divers wore rectal probes and swallowed endoradiosonde pills for each trial. The rectal data were continuously recorded, while the intestinal data were taken at 15-min intervals. On each 4-hour trial, 16 intestinal measures could be compared with the rectal values for each diver; during the 6-hour trials, there were 24 pairs of core temperature values to compare.

Two analyses were performed with these data. First, the relative relationship between the two estimates of deep body temperature was examined by computing Pearson product moment correlations between the pairs of measures for each diver on each trial. Second, the absolute difference between measures from the two recording sites was examined by subtracting the intestinal value from the rectal value over all available pairs of measurements, thus generating a difference score distribution. Sixteen correlation coefficients were computed; they ranged from 0.97 to 0.71 (mean 0.90; median 0.91; SD 0.071). All coefficients were significant beyond the 0.01 level of risk. Three-hundred and four pairs of measurements were used to generate a difference score distribution. The mean of this distribution was −0.04°C, the median was +0.03°C, and the standard deviation was 0.319.

REWARMING

Test divers were rewarmed by placing them in a tub of hot water (40°-41°C) while still in their wet suits. Core temperatures were recorded during rewarming by means of the telemetry system. Readings were taken from the endoradiosonde pill at water exit and at 10-min intervals thereafter until readings were 37°C. Postimmersion core temperature estimates were taken in this way for 12 test divers following the 4-hour cold water exposures and for 8 divers following the 6-hour exposure. Average postimmersion decline in core temperature was 0.1°C following the 4-hour exposure and 0.4°C following the 6-hour exposure; maximum fall was 0.6°C and 0.9°C, respectively. All of the declines in core temperature occurred within 20 min of exit from the cold water.

PILOT TASK PERFORMANCE

The pilot's principal tasks were the continuous and simultaneous control of heading and depth, basically a dual, compensatory tracking task. The index chosen to describe performance effectiveness in these tasks was the standard deviation of a sample of 60 measures representing each hour's performance. This index was calculated for each pilot each hour and treated as a score; smaller SD indicated higher performance levels on depth and heading control tasks. Complete data records were obtained for six pilots in the 4-hour exposures and for four pilots during the 6-hour exposures. Friedman 2-way analysis of variance (Siegel 1956) was applied to the heading and depth control scores in both 4- and 6-hour trials. Significant differences among control scores as a function of exposure hour were found for heading control but not for depth control, as can be seen from Table 3.

TABLE 3

Friedman two-way analysis of variance summary

	χ_r^2	df	*P* value
Heading error			
4-hour trials	10.4	3	$<.02$
6-hour trials	11.3	5	$<.05$
Depth error			
4-hour trials	4.8	3	$<.30$
6-hour trials	5.4	5	$<.50$

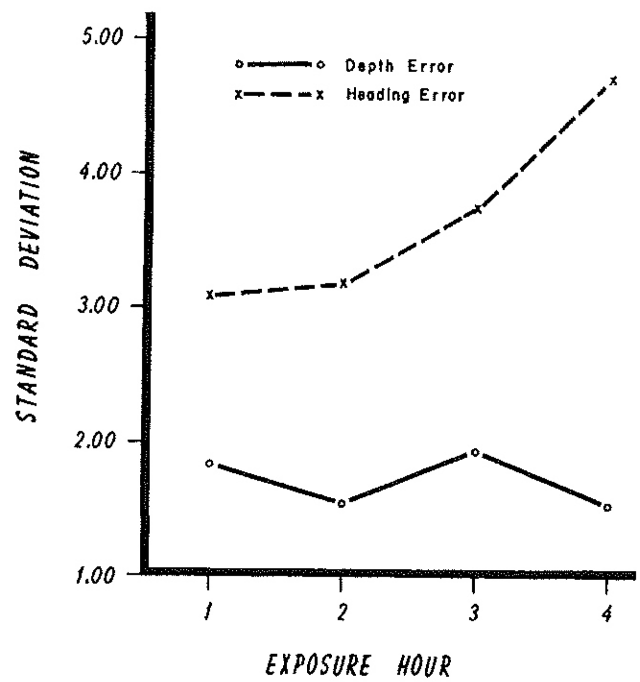

Fig. 4. Average hourly heading and depth control error during 4-hour exposures to 6°C water (n = 6).

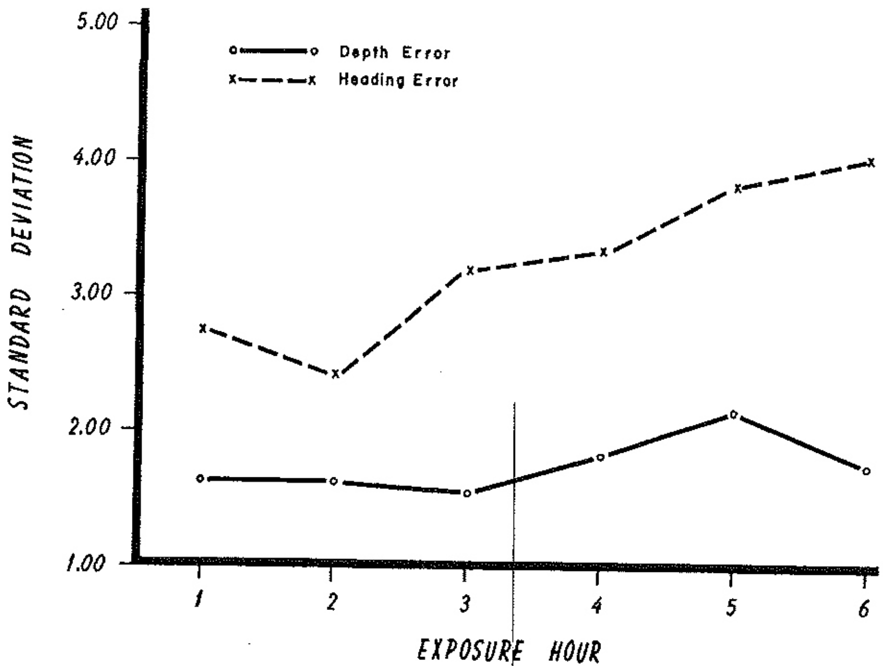

Fig. 5. Average hourly heading and depth control error during 6-hour exposures to 6°C water (n = 4)

Hourly SD were averaged across pilots and plotted in Figs. 4 and 5. Figure 4 shows the results of the 4-hour trials. Heading error consistently increased from ±3.1° in the first hour to ±4.7° in the fourth, while depth-control error fluctuated between ±1.5 and ±2.0 ft. The same general pattern of performance change over exposure duration can be seen in Fig. 5 for the 6-hour trials. Heading-control error significantly increased over time while depth-control error was constant. T tests were made to compare the first 4 hours of the 6-hour trials with the comparable hours of the 4-hour trials and none of these differences was significant. The test for significance of differences between correlated means (Edwards 1954) and an .05 level of risk were used in this analysis.

SONAR-OPERATOR TASK PERFORMANCE

Long exposure to cold water appeared to degrade performance of the sonar operators in a qualitative manner. A task complex of equipment operation, display monitoring, and data recording was required of the sonar operators during the mission phase of the test trial which followed a 4-hour exposure to cold water. All sonar operators had performed these tasks without error following a 2-hour exposure to 14°C water during training trials. Following the cold water exposure, two of four sonarmen correctly followed the procedure but omitted parts of the data record; the other two sonarmen failed to change range scales on the active sonar equipment as range to the target closed or opened beyond the initial scale setting. Furthermore, they persisted either in recording the upper-limit value on the short-range scale as range opened, or in recording the lower-limit value on the long-range scale as range closed, and did not recognize the need to change scales. All four sonar operators who participated in the long-duration exposure trials reported difficulty in concentrating on the task and in recalling the procedure.

CREW-COORDINATION TASK PERFORMANCE

Two tasks required information sharing and coordinated action between the pilot and sonar operator: acoustic homing to reference beacons at two points in the test scenario and a complex maneuver pattern during the mission phase. In the acoustic homing task the sonar operator provided the pilot with orientation information and directed him to an initial heading aligned with the sound source as determined from the passive sonar system. The pilot eventually acquired guidance information from his visual display and completed the intercept. A total of 14 acoustic homings were required in the long-duration exposures and 12 were successfully accomplished. This level of performance effectiveness (86%) compares to 10 of 12 (83%) successful intercepts recorded for these test crews during training trials in 14°C water.

The second task requiring coordinated effort was a near-shore maneuver pattern wherein the pilot controlled turns at the shoreward end, and the sonar operator controlled turns at the seaward ends of the pattern. In the long-duration, cold water exposure trials, 13 patterns were required and 12 were performed without error, a 92% level of effectiveness.

DISCUSSION

The divers participating in the Keyport cold water test series experienced a state of being more than uncomfortably cold. Postdive interviews indicated all to have suffered painfully cold hands and feet; all reported continuous, involuntary shivering which began during the second hour of each exposure. Test divers completed every trial they started, although one diver reported strong inclinations to abort his run due to severe discomfort and one diver withdrew from the test program following a 4-hour exposure. Five of the 12 test divers reported unusual experiences which included periods of double vision and blurry vision, confusion and "mental driftiness," and fears of involuntary cessation of respiratory and cardiac functions. These phenomena are not likely to have been responses attributable to psychological stress mediators such as anxiety on the part of novice divers, or to situational novelty, or to lack of familiarity with the task requirements. The test personnel were experienced Navy divers; they had been thoroughly trained in the test scenario and gradually conditioned to long-duration exposures. These men were made very cold, and yet the main index of deep body cooling–changes in core temperature–did not reflect the severity of the cold stress as observed by medical and scientific personnel or as reported by the divers. Rather than conclude that the men were not cold in a physiological sense, it is suggested that rectal-intestinal estimates of core temperature are insensitive indices of cold stress above clinically critical values. For example, minimum rectal temperatures of the five men reporting unusual symptoms were not low according to clinical standards; four were in the range of 35.5°C to 36.0°C, and one was 36.5°C.

Lack of rectal-intestinal temperature sensitivity to differences in exposure conditions can be seen from two comparisons: test divers who experienced different water temperatures for a constant time interval and test divers who experienced the same water temperature for different time intervals. Rectal temperature data were obtained from nine of the test divers during 4-hour exposures to both 14°C and 6°C water; the exposure data in warmer water were taken during training trials conducted in San Diego Bay. Mean decline in rectal temperature over the 4-hour exposure was 0.9°C in the warmer water and 1.2°C in the colder, a difference of 0.3°C; SD were 0.27 and 0.38, respectively. A direct comparison also can be made of differences in length of exposure on temperature change based on data from five test divers who experienced both 4- and 6-hour exposures to 6°C water. In the 4-hour exposure their mean change was 1.0°C and in 6-hours it was 1.2°C, a difference of 0.2°C; SD were 0.24 and 0.26, respectively. Relatively large differences in exposure conditions, a 50% increase in exposure time, and a 57% reduction in water temperature were associated with *only small differences in rectal* temperature change in repeated tests on identical divers.

While rectal temperature values were not so low as had been expected considering the severity of the exposure conditions, individual differences in temperature change were much greater than expected considering the homogeneous insulative characteristics of the divers and their wet suits. Twelve divers who ranged in body-fat percentage between 12.3 and 15.3 exhibited a range in rectal temperature change between 0.6°C and 2.1°C during 4-hour exposures to 6°C water. These differences are potentially explained by either differences in the heat-producing characteristics of the divers or in the relative contribution of respiratory heat loss. The divers can be assumed to have breathed air at 6°C over the 4-hour exposure interval and individual differences in respiration rates and volumes more likely account for the differences in rectal temperature change, since the physical condition of these men was uniformly excellent.

The extent of the postimmersion fall in core temperatures appears to be a function of the severity of exposure in terms of time at a given water temperature. While these men were able to stabilize their core temperatures at relatively high levels over long-exposure intervals, the postdive decline while in an optimal rewarming condition was as much as 0.9°C. This phenomenon eventually may place the limiting condition on safe, cold water diving.

Results of the cold water test series suggest that cold stress differentially affects performance according to complex characteristics of the task. The effects of long-duration cold exposure on compensatory tracking tasks were equivocal: performance effectiveness in one of the tracking dimensions was degraded while the other was not. Exposure effects on an individually performed procedural task, however, were dramatic and clearcut. The task complex included time-sharing, simultaneous monitoring of aural and visual information channels, and recall of procedural steps. Performance effects included both response blocking and perseveration of nonadaptive responses. On the other hand, similar procedural tasks were exceptionally well-performed under identical exposure conditions when two divers were required to exchange information and share responsibility for successful task performance.

Progress in understanding the effects of cold water exposure on task performance requires the development of more sensitive indicators of physiological cold stress, the extension of experimental tasks to include a broader range of task dimensions, and experiments which enable cold stress effects to be separated from the generic concommitants of long-duration performance such as fatigue and motivational effects.

The cold water test series at Keyport was conducted under a research contract from the Engineering Psychology Programs, Office of Naval Research, and with the support of the Bureau of Medicine and Surgery, and the Naval Ship Systems Command. The test divers were enlisted men of Underwater Demolition Team Eleven. Operational support and coordination was provided by the Naval Special Warfare Group, Pacific. LCDR Michael Strauss served as Diving Medical Officer. The hardwire instrumentation system was designed by Mr. Gaylon West of the Naval Weapons Center, and the telemetry system by Mr. Allan Slater of Emergency Care Research Institute.

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Vaughan, W. S., Jr. 1975. Température corporelle et accomplissement de tâches chez des plongeurs stressés par l'eau froide. Undersea Biomed. Res. 2(2):75-88.–Douze plongeurs de la Marine americaine ont participé à des épreuves en pleine mer d'un submersible à deux personnes. Les températures cutanées et rectales des plongeurs ont été étudiées en enregistrement continu, et des mesures d'accomplissement ont été faites pour trois types de tâches: tâches de pilot, tâches d'operateur de sonar, et tâches de coordination de l'équipe. Les resultats suggèrent un effet complexe du stress hypothermique en rapport avec la tâche. La température rectale n'a toutefois que peu de rapport avec les différentes conditions experimentales, et ne serait sans doute pas un indice assez précis du degré de stress hypothermique pour servir de corrélé de la dégradation de l'accomplissement entre les valeurs normales de la température corporelle et les valeurs cliniquement critiques.

froid
télémetrie
accomplissement de tâches
véhicule
réchauffement

REFERENCES

Beagles, J. A., and E. K. Coil. 1966. Divers' body heat loss. Research Report 1408, U.S. Navy Electronics Lab., San Diego, California 92152.

Bowen, H. M. 1968. Diver performance and the effects of cold. Hum. Factors 10(3):445-464.

Clark, R. E. 1961. The limiting hand skin temperature for unaffected manual performance in the cold. J. Appl. Psychol. 45(3):193-194.

Clarke, R. S. J., R. F. Hellon, and A. R. Lind. 1958. The duration of sustained contractions of the human forearm at different muscle temperatures. J. Physiol. 143:454-473.

Damon, A., and R. F. Goldman. 1964. Predicting fat from body measurements: Densitometric validation of ten anthropometric equations. Hum. Biol. 36:32-44.

Edwards, A. L. 1954. Experimental design in psychological research. Rhinehart and Co., N.Y. pp. 276-78.

Egstrom, G. H., G. Weltman, A. D. Baddeley, W. J. Cuccaro, and M. A. Willis. 1972. Underwater work performance and work tolerance. Tech. Rep. 51, Biotechnology Lab., University of California, Los Angeles, Calif.

Gaydos, H. F. 1958. Effect on complex manual performance of cooling the body while maintaining the hands at normal temperature. J. Appl. Physiol. 12(3):373-376.

Gaydos, H. F., and E. R. Dusek. 1958. Effects of localized hand cooling versus total body cooling on manual performance. J. Appl. Physiol. 12(3):377-380.

Keatinge, W. E. 1969. Survival in cold water. The physiology and treatment of immersion hypothermia and of drowning. Blackwell Scientific Publications, Oxford.

Lockhart, J. M. 1966. Effects of body and hand cooling on complex manual performance. J. Appl. Psychol. 50(1):47-59.

Lockhart, J. M. 1968. Extreme body cooling and psychomotor performance. Ergonomics 11(3):249-260.

Mills, A. W. 1956. Finger numbness and skin temperature. J. Appl. Physiol. 9:447-450.

O'Hanlon, J. F., Jr., and S. M. Horvath. 1970. Changing physiological relationships in men under acute cold stress. Can. J. Physiol. Pharmacol. 48:1-10.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York.

Slater, A., and S. Bellet. 1969. An underwater temperature telemetry system. Med. Biol. Eng. 7:633-639.

Slater, A., S. Bellet, and D. G. Kilpatrick. 1969. Instrumentation for telemetering the electrocardiogram from scuba divers. IEEE Trans. BioMed. Eng. BM 16: 148.

Stang, P. R., and E. L. Wiener. 1970. Diver performance in cold water. Hum. Factors 12(4):391-399.

Teichner, W. H. 1958. Assessment of mean body surface temperature. J. Appl. Physiol. 12(2):169-176.

Vaughan, W. S., Jr., and A. S. Mavor. 1972. Diver performance in controlling a wet submersible during four-hour exposures to cold water. Hum. Factors 14(2):173-180.