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A PRELIMINARY STUDY
OF
THE MEDICAL ASPECTS OF SCHNORCHEL OPERATIONS

Final Report of Bureau of Medicine and Surgery Research Project X-606 (Sub 131)

"Preliminary Study of the Effect of Schnorchelling on Submarine Personnel."

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INTRODUCTION

During the final year of the late war, the German submarine service had made extensive use of "schnorchel"*, a device which enables submarines to recharge their batteries without surfacing. This development was necessary to enable the Germans to continue submarine warfare in the face of extensive radar-equipped airplane coverage. At the war's end, schnorchel was being used as standard equipment on newer German submarines but with many problems still unanswered. Reliable information on the actual performance of schnorchel and its physiological effect on the crews was very meager. Some general statements were obtained from prisoners of war (1), (2), (3), but these were vague and at times conflicting. There was belief that long periods of schnorchelling had considerable delibitating effect on the crew (4) but no definite data on the optimum and absolute engineering limits to be imposed upon human tolerance were available.

Since it may, in the future, be desirable to equip American submarines with a similar apparatus, a study of the device and problems connected therewith was initiated. In May 1945, the project "Preliminary Study of the Effect of Schnorchelling on Submarine Personnel" was submitted to the Bureau of Medicine and Surgery by the U. S. Naval

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* The equipment known as "schnorchel" consists of a rigid streamlined housing about 30 feet long, containing two conduits, one about 11 inches in diameter serving as the intake, and immediately behind this, the second tube serving as the exhaust. The schnorchel has a hinge joint where it is attached to the submarine and may be raised hydraulically to an upright position when in use. The mushroom-shaped head of the intake tube is covered with an anti-radar material and contains a balanced, float-operated valve which closes the air intake when the water level reaches the head. The air passes down this tube through an intermediate quick-closing valve into the main air induction shaft. Thence it is conducted to the diesel compartment or to the other compartments in the pressure hull. The exhaust tube passes from the diesel engines, through the schnorchel exhaust shut-off valve, up to the exhaust tube of the schnorchel, and discharges gases through an underwater orifice.

Medical Research Laboratory, U. S. Naval Submarine Base, New London, Connecticut. Because a similar study was under consideration at the Naval Medical Research Institute, Bethesda, Maryland, the Bureau approved the projects for both laboratories with the stipulation that field trials should be conducted jointly in order to save the operating time of the submarine.

Preliminary runs were made on the R-6 using a copy of the German schnorchel, but no worthwhile results were obtained. At times fog hindered operations, while at others the sea was so smooth as to prohibit the obtaining of reliable and representative data on actual operating conditions. Moreover, due to the large size of the schnorchel and the small size of the engines of the R-6, only slight pressure changes were encountered, and so it was improbable that data obtained from this ship would be applicable to more modern submarines.

It was hoped that simulated schnorchel trials would be made on a fleet-type submarine at the Electric Boat Company, but this did not prove practicable. Letters and conferences filled the interval, and personnel visited Provincetown and Portsmouth several times for standardization runs on the U-858.

On 11, 12 and 13 September, simulated schnorchel operations were carried out at Portsmouth Navy Yard aboard the U.S.S. SIRAGO. An interim report (5) covering these operations has been submitted.

These operations were in the nature of a "feeler". After examining their results, it was felt that the only way reliable information could be obtained as to pressure changes while schnorchelling and the effects thereof on personnel was by daily schnorchelling operations for a period of about two weeks. As it turned out, in view of the poor habitability of the German submarines and the fact that they were worn out when captured, it was not possible to conduct such continuous operations for even this period of time.

A German submarine, the U-873, and an escort vessel were placed at our disposal about 1 February for two weeks of schnorchel tests. This report presents the procedures used, results obtained, and the conclusions which may be drawn from that operating period with this particular vessel.

It is obvious that a great many factors combine to determine the exact pattern of pressure changes which will be encountered at any one time. The volume of air in the submarine, design of the schnorchel, and air demand of the engines at any given speed are constant for a particular submarine. However, the speed of the submarine, wave pattern, wind velocity and direction, skill of the personnel at depth control, and the desired height above water of the schnorchel head will all vary from time to time. Consequently, one would not expect the pressure changes or intervals of opening and closing of the schnorchel head valve to be exactly the same on any two types of submarines or on any two operations of the same vessel. It should be noted that the U-873 was equipped with 4-cycle MAN engines, badly in need of overhaul or replacement. It is anticipated that somewhat different results would be obtained in a submarine equipped with 2-cycle engines. These, horsepower being equal, will consume air at a considerably more rapid rate, and, as designed at present, will not operate against as great an exhaust back pressure as will 4-cycle engines.

This study concerned itself with observations on the magnitude, duration and frequency of pressure changes, the physiological effects thereof, the atmospheric conditions in the submarine, and the ability of schnorchel operations to renew the air in the boat. The pressure data and ear, nose and throat observations were the responsibility of the U.S. Naval Medical Research Laboratory, U. S. Naval Submarine Base, New London, Conn., while the information on atmospheric conditions in the submarine and the ability of the schnorchel to renew air were determined by the Naval Medical Research Institute, National Naval Medical Center, Bethesda, Md.

PROCEDURE

Operations were carried out in the New London area. It had been hoped that representative sea conditions would be encountered in order to study performance of the schnorchel under a variety of conditions. However, sea conditions were disappointingly constant; force 1 and occasionally force 2 seas prevailed throughout the period, with no real opportunity to study behavior under varying conditions. Because of the presence of fog, operational and maintenance difficulties, as well as the consistency of sea conditions, operations were conducted on only the first three days of each of the two weeks allotted. Since a half-day was consumed in reaching the operating area, and the same in return from it, approximately two full days of schnorchelling were carried out on each of two consecutive weeks. No schnorchelling operations were conducted at night because of the necessity of making engine repairs after the day operations and because of the collision hazards involved.

The operations on 5 and 6 February will be referred to as the first schnorchel session, and those of 12 and 13 February as the second schnorchel session. The first schnorchel session consisted of ordinary schnorchel operations, and of three runs in which the loss of depth control was simulated. The second schnorchel session was taken up with ordinary schnorchel operations throughout. At this time also, determinations were made in regard to the ability of the schnorchel to renew the air in the boat.

Fifty-six crew members were aboard the submarine on each run and provided the data on the effects of schnorchel operations on personnel. All men were experienced submariners and were most cooperative throughout the experiment. They were well motivated and had the utmost confidence in their commanding officer, Lt. Comdr. Freundlich, USNR.

The ears of all subjects were examined by one of the authors, Dr. Henry L. Haines, a qualified otologist, before and after schnorchelling operations, as well as at the end of the 5 day interval between schnorchel sessions 1 and 2. Careful examination was made with both an otoscope and a nasopharyngoscope - the latter instrument providing a view of the nasopharynx and Eustachean orifices.

In addition, the men were tested in the dry recompression chamber of the Escape Training Tank at the Submarine Base, New London, to ensure their ability to take pressure. They were subjected, in groups of 20 to 25 men, to the 50-lb. pressure test, as routinely administered to submarine personnel at this activity. The pressure was built up to 50 lbs. in a period of from 6 to 10 minutes, depending on the trouble experienced by any individuals of the group.

Because pressure changes encountered were below the lower range of U. S. Navy standard barometers, readings were made with two Kollsman airplane altimeters. Pressure was recorded as feet of altitude, and later converted to inches of mercury from a table derived from the repair manual for these instruments (based on U. S. Standard Atmosphere). Two altimeters were used in order to check one against the other, and no significant differences cumulating were observed, the instruments reading to within .03 in. Hg. at all times. Pressure was recorded as in.Hg. rather than mm.Hg. as most engineering data are handled in this way, and we were working in close cooperation with the engineering officers and engineers from the Naval Engineering Experimental Station, Annapolis, Maryland.

During ordinary schnorchel operations, wartime running conditions were simulated insofar as possible, that is, the head of the schnorchel was kept as low in the water as possible in order to avoid detection. The course was laid out so that the submarine ran into the wind, downwind, and at right angles to the direction of the wind. Four-hour watches were stood in an effort to determine whether or not the maintenance of constant schnorchel depth for long periods was feasible. The men not on watch worked, slept, ate, and carried out their normal shipboard activities.

On three occasions, loss of depth control was simulated at approximately 14 meters. In the interests of safety, the head of the schnorchel was kept just below the surface of the water. At this depth the conditions of loss of depth control were not duplicated exactly in that the engine exhaust pressure did not increase progressively. However, with the engine speed remaining constant, the atmospheric pressure changes in the submarine and the rate of return of pressure to normal upon surfacing, with engines still running, would be the same as during actual loss of depth control, and it was felt that our operations approximated the actual conditions closely enough for a preliminary study.

On the first attempt, a comparatively short dip was made. Both engines ran at 2/3 speed (280 RPM), giving a speed of about 5.2 knots. On the second attempt, considerable more variation in pressure was obtained; both engines ran at 1/3 speed (220 RPM), giving a speed of 4.8 knots. In the third dip, engine speed was again maintained at 2/3 speed (280 RPM).

During these operations, air samples were taken in the engine room in evacuated glass flasks which were then sealed with mercury. Analysis for carbon monoxide was later conducted by the colorimetric technique. (6)

During the second schnorchel session, the hatches and hull openings were secured overnight, thus hermetically sealing the submarine. The CO_2 content of the air was thereby allowed to build up for twelve hours. The next morning, after diving on the electric motors, schnorchel operations were begun. Air samples were collected in evacuated glass flasks for later analysis with the Haldane gas analysis apparatus. The samples were taken at intervals in the ward-room, forward torpedo room and after torpedo room simultaneously.

RESULTS

Simulated Loss of Depth Control:

Figure I illustrates the three dips simulating loss of depth control. The occasional "jogs" noted in the graphs were caused (a) during the period of decreasing pressure by the head of the schnorchel popping out of the water and opening momentarily, and (b) during the period of increasing pressure by the head valve being partially closed by intermittent wave action.

Both engines ran at 2/3 speed (280 RPM) in the first and third operations, and at 1/3 speed (220 RPM) in the second. Considering that the slight difference in rate of pressure drop between runs #2 and 3 must be partially explained by the more frequent openings of the head valve in run #2, it would appear that in the 4-cycle engines at any rate, the engine speed was a minor factor in determining the rate of pressure drop in the boat. More observations on an American submarine in this regard are of definite importance as an aid in determining the most favorable procedure to be followed in the event of loss of depth control.

In dip #2, the head valve was submerged for 4 minutes 40 seconds, before a pressure of 18.73 in.Hg. was reached. This is equivalent to an altitude of 12,400 feet. At this point the engines slowed down but, again, somewhat different results would be expected on an American submarine. In dip #3, a minimum pressure of 19.79 in.Hg. was encountered in 3 minutes, 50 seconds, the equivalent of an altitude of 11,000 feet.

It is felt that a pressure of 16.9 in.Hg., equivalent to an altitude of 15,000 feet represents the safe limit of pressure drop. At this pressure, the haemoglobin will be 77% saturated.(7) As the pressure drops below this figure, a rapidly increasing incidence of unconsciousness will be encountered. Thus, on the basis of data obtained from indoctrination work at the Yale Aero-Medical Unit, at 18,000 feet 15-minute exposure results in an incidence of unconsciousness of 3% in untrained men, and an incidence of .09% in men who have been previously subjected to the low pressure chamber. The higher incidence of unconsciousness in untrained men is explained on the basis of the psychic trauma of the new experience.* At a pressure equivalent to an altitude of 26,000 feet, the oxygen content of the blood falls below 70% saturation within one to two minutes.(8) It should be noted that prolonged exposure, even at 15,000 feet altitude, results in a small but measurable decrement in performance. (9), (10).

During these attempts, there was a lowering of the temperature in the submarine, and the air became foggy. As the pressure dropped, the engine room filled with smoke and irritating fumes, until visibility in this space was reduced to but a few feet. The eyes of the engine room personnel lachrimated excessively, further reducing visibility. Considerable coughing and sneezing accompanied this.

The engines of the U-873 were old and badly in need of overhaul, and, as they were 4-cycle MAN engines, no conclusive statement can be made to apply to an American fleet-type submarine with 2-cycle engines in good condition. However, in this experiment, it is felt that the fumes from the engines constituted the limiting factor. Had we actually lost depth control, with constantly increasing exhaust back-pressure, the effect would have been much more pronounced.

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* Personal communication from Dr. Leslie F. Nims.

Were it not for engine fumes entering the submarine, it is believed that greater pressure drops than experienced here could be tolerated by submarine crews without danger.

It has been shown with small 4-cycle engines that, although direct engine exhaust normally contains less than 0.02% carbon monoxide, the concentration of carbon monoxide rapidly increased as the air intake was reduced toward the stoichiometric requirement (11). When up to 14% exhaust gas was added to the intake air, the CO content of the exhaust was two to five times as great as with undiluted fresh air intake (12). The possibility of obtaining toxic concentrations of carbon monoxide in the engine room during loss of depth control had therefore to be considered. Air samples were taken at the times when conditions seemed most condusive to carbon monoxide formation, i.e., when the barometric pressure was low, and the exhaust fumes were thickest. Table I shows the concentrations of CO that were obtained.

TABLE I.

Concentrations of CO Obtained During Simulated Loss of Depth Control.

Barometric Pressure (in.Hg.)	Equivalent Altitude (feet)	Carbon Monoxide Concentration parts per 1000)	Time* of Exposure Necessary for Toxic Symptoms to Appear
22.8	7,500	4.2	130 minutes
26.0	3,750	4.7	100 minutes
19.79	11,000	3.2	190 minutes

* Assuming the concentration of carbon monoxide and the equivalent altitude remained constant, time for carbon monoxide haemoglobin concentration to reach 20%.(13),(14)

It may be seen that several hours of exposure would be necessary to produce symptoms of carbon monoxide poisoning. However, in view of the extremely irritant character of the fumes at the times these samples were taken, it is felt that personnel would not be able to tolerate such atmospheric conditions for periods of more than a few minutes duration.

Of interest in regard to ear effects is the rate of return of pressure to normal, averaging about .03 in.Hg. per second (0.76 mm.Hg./sec). It should be noted that in these observations the engines continued to run after the schnorchel head valve opened. In alongside-the-dock trials of the U.S.S. SIRAGO, as reported in interim report No. 1 (5), it was noted that when the head valve was opened after the engine was shut off, the rate of pressure return to normal was too rapid to be measured with our equipment. Under such circumstances the incidence of involved ears would be expected to be much greater. In the second dip, the schnorchel head protruded well above the surface of the water after the "dip", and the pressure curve represents the pressure return with the head valve open, with the exception of the first 30 or 40 seconds when the head valve was not completely open. In the third dip, on the other hand, war conditions were more closely simulated in that the head valve was close to the surface of the water, and closed and opened several times during the return of pressure to normal. Consequently, the pressure curve is slightly distorted. These are shown in Figure I.

Tables IIA and B represent the drop of pressure from normal and the return of pressure to normal during the second dip, while Tables III A and B present the same data for the third dip.

<u>Ordinary Schnorchel Operations:</u>

It was found that judging from the effect on personnel, one schnorchel run was much like another in its over-all aspects. The pressure changes were so gradual and well within the easily tolerable ranges that it was usually not necessary to voluntarily clear the ears except at rare intervals. Pain was very infrequent; in the few cases where it did occur, it was transient and not severe.

Figure II illustrates the time intervals of opening and closing of the schnorchel head on some of the runs, as determined by direct observation of the head valve through the periscope. By operating at a depth slightly closer to the

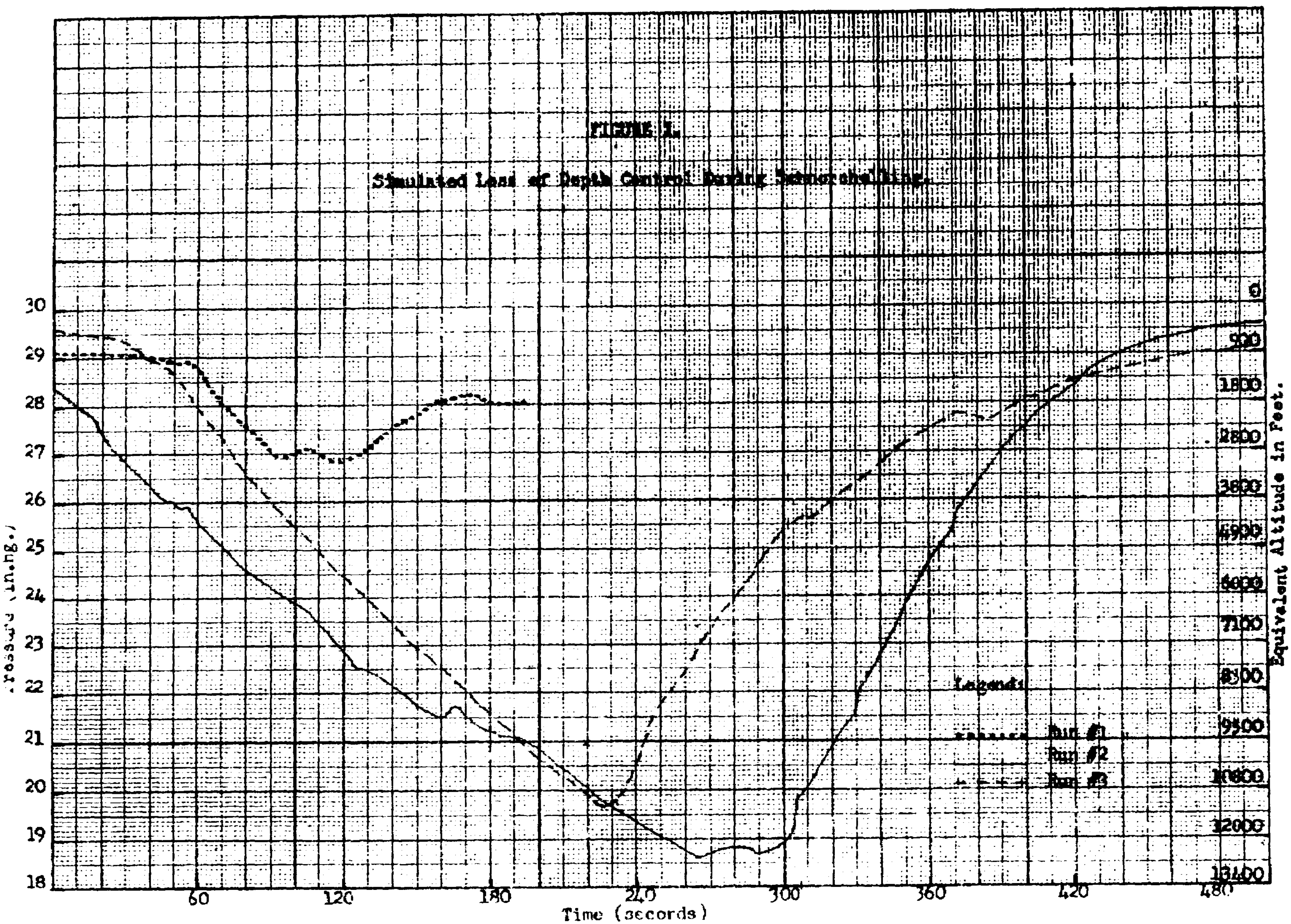


FIGURE 1.
Simulated Loss of Depth Control During Snorkelling.
Pressure (in.hg.)
30
29
28
27
26
25
24
23
22
21
20
19
18
Equivalent Altitude in Feet.
0
900
1800
2800
3800
4900
6000
7100
8300
9500
10800
12000
13400
60
120
180
240
300
360
420
480
Time (seconds)
Legend:
Run #1
Run #2
Run #3

TABLE II.

A. Pressure Drop from Normal During Simulated Loss of Depth Control, Run #2.

Pressure Change in.Hg.	Time (Sec)	Rate of Decrease in Pressure in in.Hg./sec.*
28 - 26	38	.0529
26 - 24	51	.0392
24 - 22	43.5	.0460
22 - 20	75	.0267

* "Jogs", due to schnorchel head valve being too near the surface, distort this section of curve.

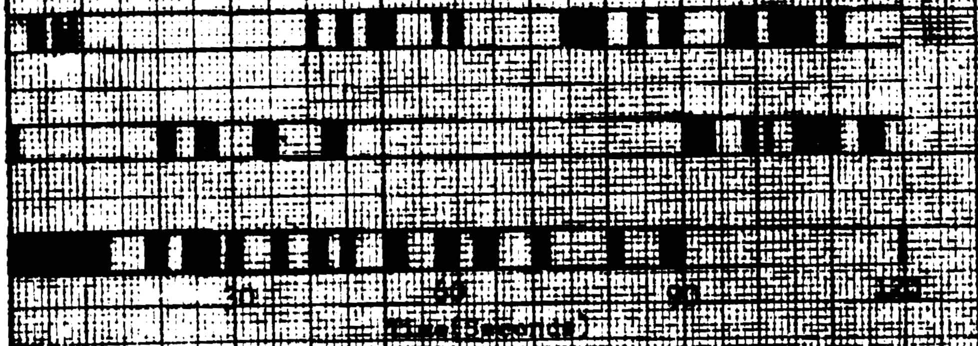
B. Return of Pressure to Normal During Simulated Loss of Depth Control, Run #2.

Pressure Change in.Hg.	Time (Sec)	Rate of Increase in Pressure in in.Hg./sec.**
20 - 22	23	.0870
22 - 24	20	.1000
24 - 26	24	.0833
26 - 28	35	.0571
28 - 29	31	.0323

** The schnorchel head valve was not completely open in the early part of this phase of the run, hence the rate of pressure rise was not as great during the first 30 seconds as it might have otherwise been.

FIGURE 11

Time Intervals of Opening and Closing of the Schnorchel Head Valve - Some Typical Runs.



Depth: [illegible]
Speed: [illegible]
Force Sea: 2
Wind: 28 M.P.H.

Legend:

Head Valve Closed

Head Valve Open

FIGURE [illegible]

Pressure Changes in Relation to the Opening and Closing of the Schnorchel Head Valve During Ordinary Schnorchel Operations.

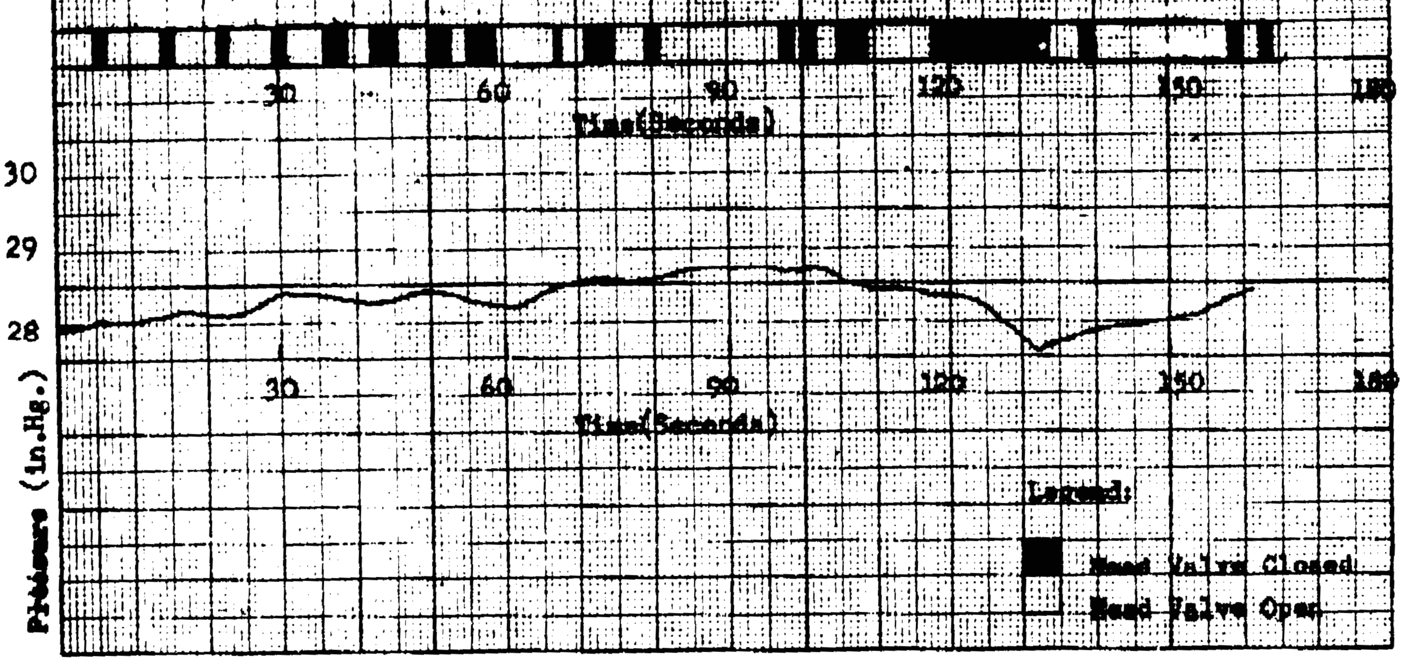


TABLE III.

A. Pressure Drop from Normal During Simulated Loss of Depth Control, Run #3.

Pressure Change in.Hg.	Time (Sec)	Rate of Decrease in Pressure in in.Hg./sec.
28 - 26	31	.0645
26 - 24	37	.0541
24 - 22	44	.0455
22 - 20	48	.0417

B. Return of Pressure to Normal During Simulated Loss of Depth Control, Run #3.

Pressure Change in.Hg.	Time (Sec)	Rate of Increase in Pressure in in.Hg./sec.*
20 - 22	20.5	.0976
22 - 24	27	.0741
24 - 26	40	.0500
26 - 28	57.5	.0348
28 - 29	80	.0125

* The rate of pressure increase to normal was diminished and at times distorted because the head valve closed occasionally. The effect is especially marked as the pressure approached atmospheric. The rate of change in segments of the curve not distorted by closure of the head valve in the range between 28" and 29" is approximately .03 in.Hg./sec., and is comparable with Run #2.

surface, the "open" intervals would be considerably longer, or the schnorchel head valve would remain open, with the period of closure, if any, of such short duration that no pressure changes could be detected. The pressure changes in relation to the opening and closing of the schnorchel head valve are shown in Figure III.

As regards the effect on the ears, the most significant phase of the pressure changes encountered is the increase in pressure. Under conditions of <u>decreasing</u> atmospheric pressure, the middle ears will automatically "vent off" via the Eustachian tubes; under conditions of <u>increasing</u> atmospheric pressure, voluntary efforts such as the valsalva manoeuver (holding the nose and blowing), or swallowing, or yawning was in some instances required.

During the return of pressure to normal during simulated loss of depth control, it was necessary for most of the personnel to employ one of these manoeuvers to clear the ears. During ordinary schnorchelling, on the other hand, when the head valve closed only occasionally, it was usually only necessary to clear one's ears on occasion.

The intervals of opening and closing of the schnorchel head valve have already been presented in Figure II. The time for the intake float valve to open, close, and open again averaged 6-8 seconds. By running fairly deep, the head valve would be closed, opening only occasionally for short intervals. By operating at a depth somewhat closer to the surface, the "open" period would become of longer duration, and occur with greater frequency. By operating at a still more shallow depth, the head valve would remain open almost constantly, with the periods of closure of such short duration that no pressure changes would reflect upon the altimeter, and the only evidence of the fact that the head valve was closing would be the "banging" that could be heard in the boat.

The barometric pressure did not return to normal when the head valve remained open but instead there was a slight negative pressure in the boat. The pressure fluctuated slightly around a mean which gradually fell or rose as the ratio of time closed to time open increased or decreased. Longer periods of closure, of from 10 to 15 seconds' duration (as from faulty depth control*) caused sufficient pressure change to be felt in one's ears. Then as the normal ratio of time closed to time open was regained, the pressure slowly returned to its previous level, perhaps necessitating voluntary "clearing" of the ears in some individuals. Most of the personnel experienced no discomfort, the sensation of pressure inequality in the ears usually being less than can be experienced by holding the nose and gently attempting to inhale.

The Ability of Schnorchel Operations to Renew the Air in the Boat:

In an effort to evaluate the ability of schnorchel operations to renew the air in the boat, the CO_2 content of the air was allowed to build up by hermetically sealing the submarine overnight. The effect of schnorchelling upon CO_2 content in the various compartments is shown in Figure IV. It can be seen that a few minutes of schnorchel operations do not suffice to renew the air in the submarine as might be expected from German claims (1), (2).

During schnorchelling the hull ventilation valve (Figure V) was closed, the air being drawn into the engine room and circulated through the submarine by means of the ship's ventilation blowers. It was not possible to draw air directly from the schnorchel through the ventilation system because a considerable volume of water entered the schnorchel each time the head valve closed. The incoming air and water were admitted to the engine room near the bulkhead, where the water could drain directly into the bilges. Keeping in mind the occasional need for rapid renewal of air in the boat, the ventilation system of schnorchel-equipped submarines can no doubt be so designed as to result in vastly improved performance along this line.

Incidence of Aerotitis Media:

In estimating the amount and severity of ear damage,

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* Faulty depth control might occur as the boat became gradually a little too heavy, from bilge water shipped in through schnorchel intake.

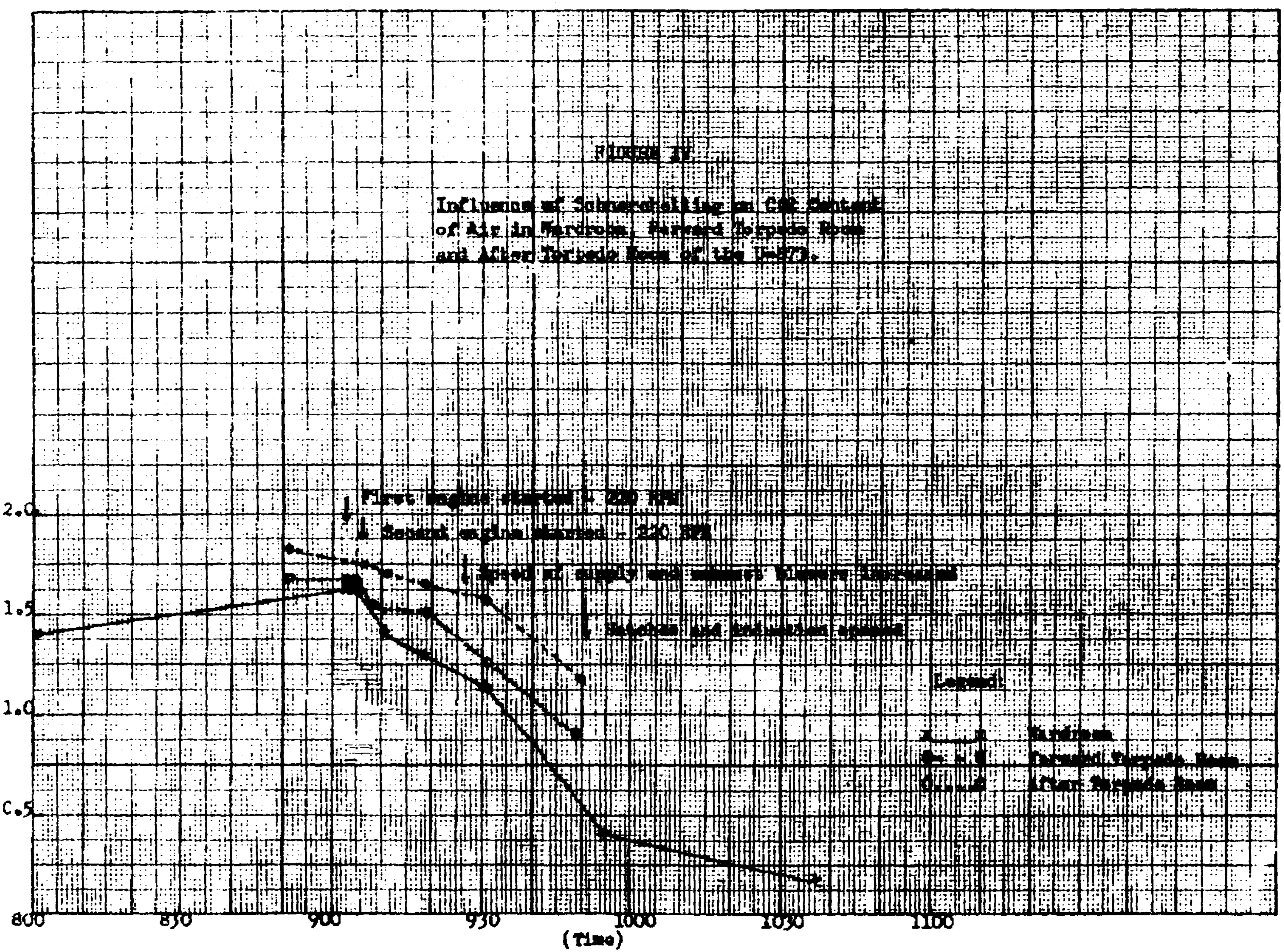
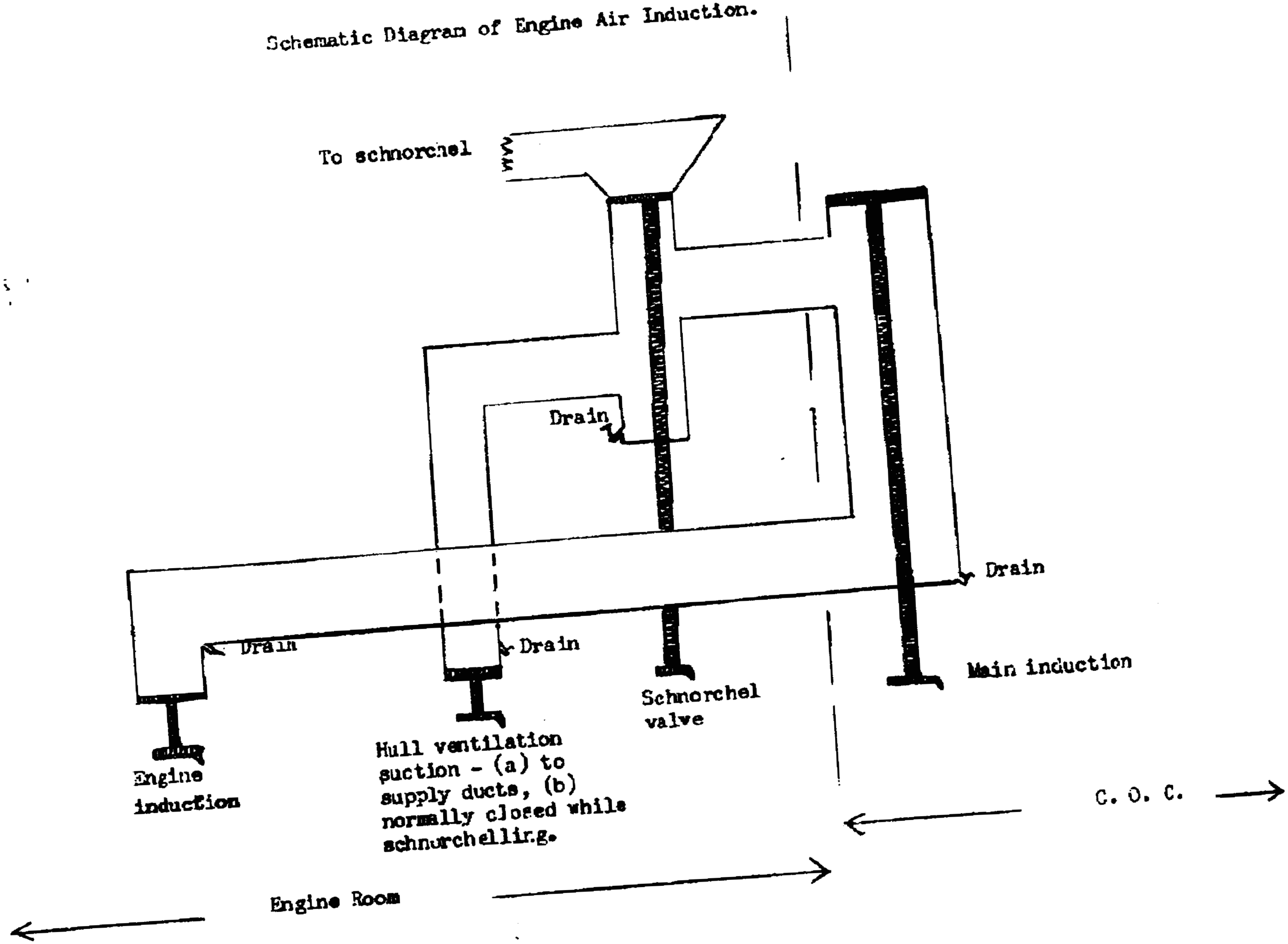

Influence of Schnorchelling on CO2 Content
of Air in Wardroom, Forward Torpedo Room
and After Torpedo Room of the U-873.
First engine started - 220 RPM
Second engine started - 220 RPM
Legend:
Wardroom
Forward Torpedo Room
After Torpedo Room
2.0
1.5
1.0
0.5
800
830
900
930
1000
1030
1100
(Time)

FIGURE V.

Schematic Diagram of Engine Air Induction.



we have used a modified form of the Teed gradation (15) of the gravity of the symptoms of aerotitis media. According to this classification, a No. 0 ear is a perfectly normal ear; a No. 1 ear will show slight congestion of Shrapnell's membrane and along the manubrium; a No. 2 ear shows very red congestion of the entire tympanic membrane; a No. 3 ear has in addition evidence of ruptured vessels in the tympanic membrane; and a No. 4 ear has extensive vascular rupture, with free bleeding in the middle ear. In the case of the No. 1 ear, the effect is transitory, the congestion disappearing in a few hours, and it is felt that there is practically no ear damage in such cases, a comparable picture being frequently produced by forcibly blowing the nose.

For purposes of this study, therefore, No. 1 ear has been considered along with No. 0, the normal ear, in the group as indicative of no ear damage from pressure variation.

In the case of Grade 4 ears, on the other hand, there is actual tissue disruption with bleeding in the middle ear cavity. In Grade 3 ears there is also found actual vascular damage in that there are ruptured blood vessels observable in the tympanic membrane, and it is not improbable that there are also ruptured blood vessels in other places in the inner ear cavity. No. 2 ears show a severe hyperemia or congestion of the tympanic membrane which persists for a day or so.

A line of distinction exists, then, between Grade 0 and 1 ears on the one hand, and Grades 2, 3 and 4 ears on the other. This will be the basis for ear involvement used in the discussion of results unless otherwise specified. To demonstrate the incidence of subjects showing the more severe pathological changes, however, tabular presentation of results will include information using three criteria for basis of difficulty:

1. Grades 2, 3 and 4 ears.
2. Grades 3 and 4 ears.
3. Grade 4 ears.

It is felt that extensive repetition of this trauma would have an eventual deliterious effect upon the subjects. Fowler has shown in his studies on pilots that "many pilots with many hours flying in commercial fields have thick and retracted drums and more or less conduction deafness.... repeated barotrauma apparently tends to favor the development of subacute and chronic otitis media (16). Ear damage of this degree, when sustained in the pressure chamber, however, does not lead to permanent loss of auditory acuity (17). It should be noted that in schnorchel operations or aircraft flight, the pressure inequality in the inner ear is brought on by the return to atmospheric pressure whereas in the recompression chamber, the negative pressure in the inner ear is equalized by the return to the surface, thus providing a form of therapy.

In view of the constant stretching and relaxing of the tympanic membrane and the interossious ligaments, it cannot be said with certainty that schnorchelling had no deleterious effects even upon those ears which show no involvement whatsoever. Whether or not this constant stretching will have any effect on a subject's ears after a long period of time can only be determined by careful observations on subjects who have been exposed to schnorchel operations over a period of months or years.

It should be borne in mind that one important difference exists between the conditions to which aviators are subjected in relation to aerotitis media and that which submarine personnel face on a schnorchel-equipped submarine during a war patrol. In the case where a flyer develops aerotitis media or other disease of the middle ear, he is usually grounded for a period of time, thus rectifying the condition before it becomes aggravated. For a sailor in a submerged submarine operating under schnorchel conditions, however, there is no relief from the constant pressure variations, no matter what pathology exists. Hence a case of aerotitis media cannot but be adversely affected by the constant pressure changes. If there is rupture of the drum and healing is delayed to the point where chronic drainage results, the possibility of permanent damage is very likely. It may be necessary to consider the feasibility of installing a pressure-proof compartment in submarines for such personnel as are unable to clear their ears for one reason or other during a war patrol.

All the subjects who had trouble did not show the same degree of trouble in both ears. The data were assembled by subjects, using the worse of the two ears if both were involved, or the bad ear if only one was involved.

As shown in Table IV, approximately 40% of the subjects showed marked hyperemia of the eardrum (this condition is present in Grades 2, 3 and 4 ears), whereas 30% had vascular rupture in addition to the hyperemia (present in Grades 3 and 4 ears), and 16% exhibited these changes, and free blood in the middle ear cavity as well (Grade 4 ears).

TABLE IV

Number and Percentage of Subjects with Involved Ears.

SESSION	BASIS OF DIFFICULTY					
	Grades 2,3 and 4		Grades 3 and 4		Grade 4	
1	23 out of 56	41.07%	17 out of 56	30.36%	9 out of 56	16.07%
2	24 out of 56	42.85%	17 out of 56	30.36%	9 out of 56	16.07%

Although the pressure changes encountered in schnorchel session #1 were much greater and more marked than in schnorchel session #2, note that the aerotitis figures correspond very closely. However, the same individuals did not necessarily fall into the same group in both sessions. For instance, a person might have a Grade 4 ear in the first session and a Grade 2 in the second, or vice versa.

Of the fifty-six subjects on whom data were obtained during these schnorchel operations, thirty-two or 57.14% had no ear involvement during either of the schnorchel sessions. These observations are too few to permit any generalizations, but it appears from this that the presence or absence of ear involvement in an individual during one run would serve to predict the presence or absence of ear involvement in that individual during other schnorchel runs.

Effect of Sleep During Schnorchelling:

In both schnorchel sessions, the percentage of sleepers who had involved ears was much greater than the percentage of ear involvement found among subjects who stayed awake. Tables V A,B and C present results in tabular form.

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TABLE V

Number and Percentage of Sleepers Having Involved Ears Compared to Number and Percentage of Non-Sleepers Having Involved Ears.

A. Basis of Difficulty : Grades 2,3 and 4 Ears.

Session	Total Sleeping	Total Awake	No. and % Having Involved Ears. Sleeping		Awake	
			No.	%	No.	%
1	19	37	12	63.15	11	29.73
2	16	40	11	68.75	13	32.50

B. Basis of Difficulty : Grades 3 and 4 Ears.

Session	Total Sleeping	Total Awake	No. and % Having Involved Ears. Sleeping		Awake	
			No.	%	No.	%
1	19	37	11	57.89	6	16.22
2	16	40	10	62.50	7	17.50

C. Basis of Difficulty : Grade 4 Ears.

Session	Total Sleeping	Total Awake	No. and % Having Involved Ears. Sleeping		Awake	
			No.	%	No.	%
1	19	37	4	21.05	5	13.51
2	16	40	4	25.00	5	12.50

Effect of Cold and Sinusitis on Subjects During Schnorchelling:

In both schnorchel sessions, the percentage of cold sufferers (as determined by ENT examinations) who had ear involvement was

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approximately twice that of those who had no colds or sinus trouble but did have involvement of their ears during schnorchelling. This is shown in tabular form below.

TABLE VI

<u>Number and Percentage of Cold Sufferers Having Involved Ears Compared to Number and Percentage of Persons Without Colds Having Ear Involvement.</u>

A. Basis of Difficulty : Grades 2,3 and 4 Ears.

Session	Total With Colds	Total Without Colds	No. and % Having Involved Ears. With Colds No.	%	Without Colds No.	%
1	15	41	10	66.67	13	31.71
2	15	41	10	66.67	14	34.15

B. Basis of Difficulty : Grades 3 and 4 Ears.

Session	Total With Colds	Total Without Colds	No. and % Having Involved Ears. With Colds No.	%	Without Colds No.	%
1	15	41	7	46.66	13	31.71
2	15	41	7	46.66	10	24.39

C. Basis of Difficulty : Grade 4 Ears.

Session	Total With Colds	Total Without Colds	No. and % Having Involved Ears. With Colds No.	%	Without Colds No.	%
1	15	41	3	20.00	5	12.19
2	15	41	3	20.00	6	14.63

Value of Pressure Chamber in Predicting Performance:

It was expected that the pressure chamber would serve as an aid in the selection of those subjects who would encounter ear involvement during schnorchel operations, hence the men were given the 50-lb. test in the dry recompression chamber as described in the section on Procedure. However, in this particular case, it did not seem that the chamber test was successful in culling out those who would have trouble during actual operations. All the men tested were able to pass the 50-lb. pressure test, but on examination after the test, there were 6 who were found to have ear involvement in the chamber, that is to say, had a Grade 2, 3 or 4 ear. Chamber data are available on 46 of the 56 subjects used. Of the six men who had trouble in the chamber, 3 had trouble during schnorchelling, and they had difficulty during both sessions. On the other hand, 16 men who had involved ears during the first schnorchel session and 17 who had involved ears during the second schnorchel session passed the chamber test without any evidence of ear damage.

In this connection, however, it should be noted that all the subjects were experienced submarine personnel, and there were, therefore, no consistent chamber failures among the group. All of the men had undergone previous selection and had taken the test at least once previously, many of them having taken it several times in the past. It is felt likely that men who would fail consistently in the pressure chamber as evidenced by ear pain and inability to take the 50-lb. pressure test would very likely also experience difficulty and probably pain during schnorchelling operations. It would be valuable to run at some future time a group of consistent tank failures under schnorchel or simulated schnorchel operations to determine the value of the chamber selection in this regard.

Further work regarding the use of the recompression chamber as a measure of selection of personnel for schnorchel operations is necessary. It is felt that the first few pounds of pressure administered are significant in the selection of candidates, and that more rigid control of the rate of administration of the first few pounds would result in more satisfactory screening of candidates. Better results might be obtained with a more rapid administration of pressure, in order that the rate of change of a volume of air might approach the rates of change encountered under schnorchel conditions.

It must again be emphasized that two schnorchel sessions do not yield sufficient data to permit any positive statements, but serve rather to show certain general trends, to focus attention on problems to which more specific answers are required and on which a greater number of observations must be made when the opportunity presents itself.

SUMMARY AND CONCLUSIONS.

1. Preliminary studies were carried out upon the effects of schnorchelling on submarine personnel. Four days of schnorchel operations, divided into two sessions a week apart, were observed on the captured German submarine U-873, and the effects thereof upon 56 American crew members were determined. The short period of schnorchel operations and the limited number of subjects, as well as the differences between this submarine and those to which schnorchel might be adapted, prevents any final, clearcut answers to the many problems associated with schnorchel operations. Close medical observation and study are essential during any further use of this device.

2. Pressure variations were usually less than 1 in.Hg. during ordinary schnorchel operations, and one soon became accustomed to the constant pressure variations.

3. During simulated loss of depth control, the pressure dropped to 18.5 in.Hg. (equivalent to an altitude of 12,400 feet) in a period of 4½ minutes. The most rapid rise in pressure recorded during the return of pressure to normal was at the rate of 0.1 in.Hg./sec., the average rate being approximately 0.03 in.Hg./sec.

4. On this submarine the limiting factor during simulated loss of depth control was the presence of exhaust fumes in the engine room. The highest carbon monoxide concentration in the engine room at these times was 4.7 parts per 10,000, but the irritant character of the fumes was such that exposure for more than a short time could not be tolerated.

5. 40% of the personnel developed aerotitis media of Grades 2, 3 or 4. Grade 4 ears, with free bleeding in the middle ear, was present in 16% of the subjects. The same incidence and severity of ear damage was encountered in ordinary schnorchel operations as in simulated loss of depth control. During ordinary schnorchel operations, however, no pain was associated with the damage, and there was no apparent consciousness of it, whereas during simulated loss of depth control, it was necessary to voluntarily clear the ears, and a few of the men who had colds complained of moderate pain.

6. In these subjects, the presence or absence of aerotitis media during the first schnorchel session was a good predictor of the presence or absence of aerotitis media during the second schnorchel session. Administration of the routine 50-lb. pressure test did not satisfactorily predict the occurrence of aerotitis media during schnorchelling. In this regard, more observations are necessary to determine the need for changing the test procedure in the selection of personnel for schnorchel operations.

7. A higher incidence of aerotitis media was encountered in those personnel who slept during schnorchel operations (63% as compared to 29%) and in those who were suffering from colds (66% as compared to 31%).

8. No nausea, dizziness, or diarrhea were experienced by any of the crew, although the effects had been ascribed to schnorchelling by the Germans. (1), (2).

9. Schnorchel operations did not serve to rapidly renew the air in the boat, as had been claimed by German prisoners of war. (1), (2).

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