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UNDERWATER SOUND LOCALIZATION IN HUMANS

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In air, man depends on his directional sense of hearing to locate the source of sounds, to warn him of approaching objects which emit acoustical signals, to differentiate among competing signals, and so on. Indeed, these processes are reasonably well developed and provide humans with important sensory information as they operate in their normal milieu. On the other hand, both theory and empirical evidence would predict that, in the underwater environment, humans will either totally lose their sound localizing capabilities or have them seriously impaired. For example, Bauer and Torick (1965) suggest that when an individual is submerged "Sounds appear to arrive from nowhere. The location of a friend or foe becomes a matter of dangerous conjecture, and reverberant sounds mix with direct sounds into an unintelligible jumble." At that time, this observation seemed confirmed by de Haan (1956), Dudok van Heel (1962) and others.

Directional perception of sound in air is based on the utilization of phase (time-of-arrival) and/or intensity information provided by the arriving signal to the auditory mechanism. For the low frequencies, phase is most important and the arrival of sound at one ear (vs. its arrival at the opposite ear) can vary up to 0.6-0.7 msec. At higher frequencies the head creates a shadow effect which in turn produces a marked intensity difference between the two ears. Mills (1958) suggests that the division of the frequency range (for sinusoids, anyway) occurs at 1400 Hz. with temporal cues dominant below that level and intensity cues dominant above it. Quite obviously, however, time or intensity data of the magnitude cited are adequate for effective sound localization in air.

In fluid environments, however, a different situation exists. First, sound velocity is greater in water than it is in air by a factor of from four to five (depending on salinity, temperature, etc.). Due to this many fold increase in the speed of sound, the time interval of an arriving signal across the head would be correspondingly diminished, thus virtually eliminating the directional perception attributable to time delay (phase). It is as if, in the air environment, the individual's head had shrunk to the size of a golf ball. In any case, the time-of-arrival data available for processing at the cortex is dramatically reduced once the head is immersed in water.

Theoretically, a second factor also operates to reduce underwater sound localization; it is concerned with the intensity differential (shadow effect) that permits the auditory processing in air of the directionality of higher frequency signals. Briefly, this effect is present in air because of the mechanical impedance of the head; i.e., in air the impedance mismatch between air and solids (such as the head) is sufficiently great so that the head constitutes an effective acoustic barrier. This relationship does not hold in water as the impedance of the head is similar to that of the fluid. Therefore, sounds virtually go through the skull reducing by a substantial magnitude (or eliminating altogether) this shadowing effect and its concomitant intensity differential. Such a situation further reduces man's potential ability to localize sounds underwater.

In addition to theory and the observations of such workers as Bauer and Torick and Dudok van Heel, there is other powerful negative evidence in this regard. Such evidence resulted from a series of experiments carried out by the author and an associate (primarily, Brandt and Hollien, 1967, 1969, and Hollien and Brandt, 1969) in which underwater auditory acuity was thoroughly investigated. The end product of these and other studies has resulted in a hypothesis that man's underwater hearing sensitivity is somewhat reduced but otherwise normal with the following restrictions: 1) the external and middle ear do not function underwater (or function only minimally) and 2) submerged hearing is accomplished by transmission of the acoustic signal from the water to the cochlea via the skull. If this contention is correct--and the evidence in this regard now appears overwhelming--one must begin to think of underwater auditory function in totally new and different terms. For most practical purposes, man must be considered to be "one eared" underwater; the term "bone conduction" acquires new meaning, "air (water) conduction" as used currently in Otology and Audiology has little or no validity. Moreover, the implications relative to underwater sound localization are substantial.

It is this alteration of the acoustic pathway which is crucial to understanding underwater localization of sound if, indeed, such a function exists at all in man. That is, the external and middle ears appear to be removed from the acoustic pathway in a fluid medium because of impedance mismatches; impedance mismatches occur because of force and amplitude relationships. Specifically, sound travels through a gas in a high amplitude, low force (**Af**) relationship; through fluid as high force, low amplitude (**aF**). The external and middle ear function to increase **F** in sound energy from its airborne level to a level that will interface properly with the fluid contained in the cochlea. Hence, for hearing in air: $\mathbf{Af} \rightarrow \mathbf{aF}$. When man is underwater, however, the process is one of: $\mathbf{aF} \rightarrow \mathbf{Af} \rightarrow \mathbf{aF}$ and the serial impedance mismatches are so great (especially the one at the first transform) that these conditions effectively render inoperative the elements of the external auditory mechanism which are so important to sound localization. On the other hand, the relationship between fluid and the skull (and brain fluid) is one of a favorable impedance relationship. Hence, hearing underwater is normal except that the change in the acoustic pathway reduces acuity and the acoustic distance between the ears--or more accurately, the two cochleas--is substantially reduced. If the above information and conclusions are added to the previously cited theory and data, the total effect is one of a strong argument against any effective underwater sound localization in man.

On the other hand, informal reports by many divers have continued to stress that they often felt they could do at least some primitive localizing of sound. And, more important, Feinstein (1966) reported a contrary opinion based on his own research and the very early work of Ide (1944). Seemingly, however, the results by Feinstein and by Ide could be accounted for and the negative evidence appeared overwhelming. Thus, late in 1967, a pilot study was undertaken which was designed to settle the question. At that time I frankly believed the results would support the negative position; instead, they were in startling contradiction of that position.[1] Accordingly, an

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[1]Since that time a number of other studies have been reported. The most notable are: Feinstein (1969), Anderson and Christensen (1969), and Leggiere, McAniff, Schenck and van Ryzin (1970). The results of these investigations will be discussed later.

extensive series of experiments were designed and carried out; the first, and most important, of the series is described here.

METHOD

The first step necessary was to develop a rigorous methodology that would permit valid and appropriate research to be carried out. In this regard, it was imperative 1) that subjects could be placed in a reasonable anechoic space with no reflective surfaces within 40 feet of them; 2) that all stimuli, responses and subject position could be controlled with near-laboratory precision; 3) that none of the sound sources (projectors) would be placed close to the subjects; 4) that the entire experimental milieu permit calibration; 5) that the experimental stimuli consist of a number of different acoustic signals; 6) that the method permit a large number of subjects to be studied; and 7) that the subjects used should be experienced divers with average to good auditory acuity. The rationale for imposing the above criteria on the experiment seem obvious; they were accomplished as follows.

Test Site and Apparatus:

The test facility was made available by the Underwater Sound Reference Division (USRD) of the Naval Research Laboratory, Orlando, Florida. This facility is located at Bugg Spring, about four miles southwest of Leesburg, Florida. Since a detailed description of the site is available (Brandt and Hollien, 1967, or Hollien, Coleman, Thompson, and Hunter, 1970) only a brief review follows. The USRD field facility consists of a deep (170') fresh-water spring (temperature a constant 22^{o} C) upon which is located a large floating barge with two laboratory buildings situated one on either side of a well through which equipment can be lowered to any desired depth. A general view of the research site may be seen in Figure 1; it met the first two criteria as well as the fourth.

In order to meet the other criteria, a Diver Auditory Localization System (DALS) was designed and constructed. the DALS design was based on DICORS (Diver Communication Research System) which was originally developed for diver communication research by Hollien and Thompson (1967). In general, DALS is an open framework diving cage, constructed of poly-vinyl chloride tubing (PVC tubing is acoustically invisible underwater); the modification consisted of coupling a series of five 8.5-foot arms to the top of the system. These five arms were located to allow J-9 projectors to be placed at ear level at a reasonable distance from the center of the subject's head and at angles to the diver/subject of 0^{o}, 45^{o}, 90^{o}, 270^{o}, and 315^{o}. A rough schematic drawing of DALS may be seen in the lower half of Figure 2; an incomplete photographic view in Figure 3. This photograph does not show the total system as it was so large it could be assembled only underwater--and even there it was too large to photograph. However, the general pattern of the system may be seen from the figures.[2]

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[2]DALS incorporated a number of diver safety features also, including a buddy line to the surface, an emergency air supply, an emergency switch coupled to an alarm at the surface and a TV monitoring system.

As stated, five J-9 projectors were used to provide the sound sources for the project. In order to calibrate them, an F36 hydrophone was fixed to DALS at a position corresponding to the center of the diver's head. The signals from the J-9 projectors were received by the hydrophone and transmitted by cable to an amplifier (Ithaca model 250) and a divider network on the surface. The signal was then led to a graphic level recorder (General Radio type 1521-B) coupled mechanically to the beat-frequency oscillator.

The signal voltage and frequency were monitored by a voltmeter (Ballantine model 302C), a frequency counter (Hewlett-Packard model 512A), and an oscilloscope. All of the surface equipment was located in a large, air-conditioned laboratory room on the test facility platform (see Figure 3). Each of the five J-9 projectors was calibrated to produce the same SPL reading at the F-36 hydrophone (for all experimental signals) in order to assure that subjects would not be receiving cues on the basis of intensity differences.

Transducers:

The underwater transducers used in this investigation were the USRD type J-9 projector with an audio-frequency range from 40 to 20,000 Hz. The sound radiating surface is a $2\frac{1}{2}$-inch diameter magnesium diaphragm supported by a rubber suspension system that permits large linear movements of the diaphragm. The diaphragm is driven by a moving coil positioned in the field of a permanent magnet. A stainless-steel housing contains a pressure compensating system which automatically adjusts the pressure on the rear of the diaphragm to compensate for the external water pressure.

The F-36 hydrophone is a lead zirconate-lead titanate transducer with an operating range of 10-20,000 Hz. The sensitive element consists of seven capped lead zirconate-lead titanate cylinders mounted one above the other in an 8-inch line. These elements are housed within an oil-filled butyl boot over a framework of six steel rods that provide protection and support without affecting the acoustic characteristics of the transducer.

Experimental Stimuli:

Sinusoids of 250, 1000, 6000 Hz and thermal noise were used as experimental stimuli. The stimulus presentations consisted of five pulses of the experimental frequency set up as 500 msec bursts at 40 dB (110 dB SPL) re: average underwater hearing threshold for the diver/subjects. The stimulus presentations were gated ON and OFF with the duty cycle of 500 msec and a 25 msec rise-fall time.

Subjects:

The research was carried out on 17 adults (10 males and 7 females) obtained from the faculty and staff of the Communication Sciences Laboratory, University of Florida, and the U. S. Navy Mine Defense Laboratory (now NSRDL), Panama City, Florida. The mean ages of the males and females was 29 and 27 years, respectively; the age range for males was 18 to 48 years and for the females, 20 to 35 years. All subjects were at least reasonably competent divers with experience in taking hearing tests in air (all had essentially normal hearing) and participating in underwater projects of this general nature.

Experimental Procedure:

A general understanding of the experimental procedure may be obtained by reexamining Figure 2. DALS was lowered by a winch to an ear depth of 40 feet. The diver, wearing open-circuit SCUBA equipment and a wet suit jacket, descended to the cage, seated himself, locked his arms over a bar provided for subject positioning (see again Figure 3), and placed a lead-weighted belt over his legs to keep him firmly on the seat. During the experiment, subjects were free to move their head but not their body.

The experimental signals were presented to diver/listeners five times from each of the five transducers, for a total of 25 presentations of each stimulus. As stated, they responded by means of the five-position underwater switch coupled to an IBM key punch at the surface. Moreover, these responses were individually verified (by having an assistant check a light panel paralleled to the key punch) before subsequent stimuli were presented. In this manner, errors in recording data were avoided and subjects were given ample time to respond to each stimulus presentation. After the subject's response was recorded, a new stimulus was presented and the procedure was continued until all 25 presentations of each frequency were completed.

RESULTS AND DISCUSSION

As stated, this experiment was concerned with the ability of divers to localize underwater sound sources which were presented at reference angles of 90°, 45°, 0°, 315°, and 270°. Table 1 lists 1) the ranked individual scores obtained for each subject, 2) their mean overall scores, 3) the mean for each stimulus, and 4) the standard deviations associated with each of the four stimuli. Inspection of the table reveals that the overall performance of the 17 subjects was clearly above chance level as, on the basis of chance alone, it would be expected that the scores would cluster around 20%. Only 10 of the 68 scores were close to chance, only one individual (subject 17) had an overall score of less than 30% and the overall mean of 43.8% (based on 1700 S-R presentations) is more than double chance. Thus, it must be concluded immediately that humans show some ability to localize sound underwater and that localization is best for low frequency or broad-band signals.

Confirmation of this position can be provided by current research. For example, Feinstein (1969) has reported data demonstrating that human subjects were able to localize sounds with as little as 15° error from the midline in a right-left discrimination. Leggiere, McAniff, Schenck and van Ryzin (1970) report that their six subjects demonstrated some localization ability especially at the (low) frequencies of 600 and 800 Hz. Moreover, Anderson and Christensen (1969) who performed an experiment roughly patterned after Feinstein's (1966) confirmed, at least, the right-left discrimination data. Finally, it must be remembered also that Ide (in his 1944 report which was classified for many years) provided some powerful results in this regard. He reported that his subject/divers were successful in localizing an underwater sound source. Specifically, in his research, several men swam a distance of approximately 300 yards (with face plates blacked out so that they could not see) to an ammonia jet which acted as the sound source. Ide reported that one man, "swimming entirely underwater and guiding himself by binaural perception of the jet, followed a 300-yard curved course through a strong cross-current and came up right beside the jet."

Of course, when certain other species of animal are considered, there perhaps should be little cause for surprise that man can localize underwater sounds--at least to some extent. Indeed, localization studies utilizing amphibious marine mammals such as the common harbor seal, Phoca vitulina, (Mohl, 1962) and the California sea lion, Zalophus californianus, have indicated that these mammals are able to successfully localize sounds in fluids (Gentry, 1967). The fact that these amphibious mammals[3] have been able to successfully adapt to the demands of an underwater environment is relevant to man's potential adjustment since, as Feinstein points out, these animals "appear to have adjusted to sensory demands of hydrospace without the benefits of acoustically isolated ears or specialized relationships between the bones of the middle ear."

On the other hand, it is clear from the data that this human auditory function is not nearly as effective underwater as it is in air and attempts must be made to obtain information concerning the nature of this type of sensory processing if the ability is to be understood and perhaps developed. Included among these issues must be 1) the extent (and the limitations) of this capability, 2) the actual mechanisms by which it is accomplished, 3) if (and how) the facility can be enhanced, and so on. A more detailed analysis of some of the data obtained by the present investigation may serve to provide some clues about the mechanisms that are operating and lead to specific postulations concerning these relationships.

For example, Table 1 lists the standard deviations for each of the stimulus conditions. An inspection of these values, and each of the subject's scores, demonstrates that there is variability in performance among and within subjects. This finding is not unusual in underwater localization studies as Feinstein also reports considerable variability among his subjects--as did Ide and Leggiere, et al. Moreover, localization studies in air are not without variability either. However, it is difficult to make valid comparisons in this regard because the two situations are so dissimilar. For example, the methodologies employed for localization studies in air are often quite different than the techniques utilized here; degree of error rather than standard deviations often are reported. The acoustic parameters are different, and, in the underwater milieu, localization is being accomplished without the middle and external ears. Further, in attempting to localize sounds underwater, the subjects in this experiment were attempting auditory tasks that were quite unusual for them. Hence, their inability to perform consistently could be due primarily to unfamiliarity with the situation--especially with respect to the intrasubject variability. On the other hand, it is well known that individuals differ considerably in their auditory abilities and the intersubject variability may be indicative of such a spread in auditory skills. Thus, it is possible that some individuals will natively exhibit far greater potential than others in decoding underwater signals for localization purposes.

The data can be analyzed in other ways, also. For example, in order to determine the extent to which subjects' responses are distributed over

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[3] The echo and sound location ability of dolphins and several subspecies of larger whales is well documented also. However, the evolution of these mammals has resulted in structural changes favorable to localization.

the five possible sound-source locations, magnitude of error estimates were determined for each of the stimulus conditions and for all conditions pooled; Table 2 presents these data. Specifically, a five-by-five matrix was constructed which listed the five stimulus locations and the corresponding responses of the 17 subjects to each of these possible locations. Inspection of Table 2 will reveal that the errors are distributed more or less "normally" around the actual location. Indeed, the majority of the subjects' responses were distributed between the correct projector location and the transducer on either side of that location. If, in this case, we define "correct response" to be within a quadrant, performance was 78% for 90°; 86% for 45°; 73% for 0°; 90% for 315°; and 81% for 270°.

The quadrant data are presented in Table 3 in still a different manner and may be found in the two left hand columns of that table. In this case, the position array is collapsed rather than the stimulus type array. Surprisingl high scores are evident. A final rotation of the data--that relevant to sidedness--also is presented in Table 3 (see the two right hand columns). Here only the data for the left (270° and 315° projector positions) and right (45° and 90° projector positions) responses are analyzed; 0° data are ignored. Again the level of correct responses is high. It is of incidental interest to note that the scores are slightly better for the left side and the raw data indicate that about 6% more responses were made to the left. In short, it is apparent that when an individual is required only to identify that a sound source is coming from a quadrant or one side or the other, performance in water somewhat more closely parallels that in air. Is it possible then that this finding suggests a potential for improving underwater sound localization by training?

A final relationship among the data can be noted. Examination of Tables 1 and 3 will reveal that, no matter how the data are analyzed, the best localization occurs for thermal noise and 250 Hz. These data, which are consistent with those of Leggiere, et al., suggest that broad band signals and low frequency sinusoids possibly provide more cues than do narrow band signals and sinusoids of higher frequencies. Moreover, several of the divers reported that they actually seemed to "feel" the arrival of these two signals (on their legs, hands or face) and these tactile sensations appeared to assist them in localizing the direction of the source.[4] Admittedly, the data for these low frequency/broad band signals would argue that time information is important to underwater sound localization. However, the reports of physical sensation corresponding to their onset would argue that kinesthetic cues may be combined with the auditory information to produce higher performances for these experimental conditions. In any case, it is obvious that further research is necessary before the role of such stimuli/space relationships will become apparent--especially with respect to the audition mechanisms that operate to permit underwater sound localization.

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[4]That sound localization is possible via the human skin is well established. See, for example, Bekesy (1955, 1957) and Gescheider (1965).

The above patterns reveal certain characteristics of underwater sound localization ability in humans. First, it is essential to concede that this auditory function is considerably poorer in fluid than it is in the gaseous milieu of air. Secondly, the general patterns among the data especially suggest a reasonably similar (but impaired) type of processing for water as for air. Hence, it would seem appropriate to discuss mechanisms that might possibly explain the processes of underwater sound localization as observed in this investigation.

It has been shown previously that the mechanism for underwater hearing is bone conduction, hence, the two "ears" cannot operate to provide differential auditory information to the cortex. Further, sound in water operates in a manner detrimental to the usual localization mechanism. Specifically, because the head does not operate as a sound barrier underwater as it does in air, the intensity difference at each ear should be eliminated by the water and because sound in water travels approximately four to five times faster than in air, phase or time-of-arrival cues also are greatly reduced. In fact, based on the inter-aural distances encountered in man, it can be expected that sound would arrive at one cochlea only microseconds before it arrives at the other. Actually, however, it would appear that even these small arrival time differences (0 to about 67 microseconds at angles of 0° and 90°, respectively[5]) may provide at least part of the information utilized by an individual to localize underwater sound sources as it has been reported that the ear is able to resolve time differences on the order of only seven microseconds (Tobias and Zerlin, 1959; United Research, Inc., 1962; Zerlin, 1969). Thus, if the two cochleas can resolve time differences of less than 50 microseconds, say, the type of processing described above would permit some sound localization. Confirmation of this postulate is provided by Feinstein (1969) who described a problem he had experienced with his divers on certain homing and navigational tasks. He found that his subjects did quite poorly with these tasks because they could not hear the acoustic signal. He then cut a horizontal strip from their wet suit hoods just above the faceplate and his subjects not only could hear the signal but they accomplished the navigational tasks in a reasonable manner. His experiences appear to be a rather powerful confirmation of the argument presented above.

If time differences are important for underwater localization, an explanation is necessary to account for localization at 0°--where no time delay would be present. In this regard, it seems reasonable to assume that with no arrival-time differences between the two ears, a signal would be recognized as coming from directly forward and any arrival-time difference greater than zero would be interpreted as coming from a source somewhere other than 0°. Further, when time separation peaked, auditory processing would suggest that the sound was at a 90° angle to the head; the ear first receiving the sound would be recognized as corresponding to the side from which the sound was coming. Of course, under these conditions, one would expect even more severe front-back confusions than are commonly found in air. Thus, it would appear

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[5] In fresh water, sound travels at $1.48(10^5)$ cm/sec at 20° C. Correcting for the temperature difference, the speed of sound at Bugg Spring is $1.489\ (10^5)$ cm/sec. If the two cochleas can be considered to be 10 cm apart, the travel time between them is 67.2 microseconds.

that time-of-arrival information is more important to underwater sound localization than is amplitude difference information. However, the highest frequency utilized in the present experiment was 6000 Hz--a frequency well below[6] any that would be primarily amplitude dependent. Nevertheless, it must be conceded, that most underwater sounds useful in avoidance behavior, navigation, homing, and the like would be within the range studied in this experiment.

Another explanation to account for underwater sound localization has been proposed--one that is somewhat different than either the traditional time-of-arrival or amplitude explanations of sound localization in air. Brandt (1970) has suggested a mechanism which would incorporate a difference in loudness at the two cochleas produced by a differential sensitivity of the skull to free-field sound sources. However, some information exists that would appear to negate this hypothesis as Zwislocki (1957) and Nixon and von Gierke (1959) have stimulated subjects (in air) by a free sound field bone conduction stimulus and were unable to obtain differential threshold shifts as a function of sound source location. However, their studies were only for angles of 0° and 180° (front-to-back differences). Recently, Isele, Berger, Lippy, and Rotolo (1968) reported differential sensitivity of the auditory system for bone conduction as a function of five different placements of a bone conduction oscillator. The results of this study suggest that a subject may be able to localize a skull conducted stimulus on the basis of intensity differences alone. Such a relationship should hold for underwater hearing also. That is, a loudness difference may result (for underwater sound sources of equal intensity) because of the differential sensitivity of a subject's head to skull conducted stimulation. In the case of this experiment, an auditory stimulus would strike the head at a different location for each of the five different angles tested and, if Brandt's postulate held, localization at the level experienced could occur.

In summary, it is apparent that man can localize underwater sound sources somewhat crudely but considerably better than previously suspected. It is apparent, however, that this capability is considerably poorer in water than it is in air. Mechanisms involving interaural distance and differential skull sensitivity are postulated to account for this localization ability but before more definite statements can be made, further appropriate research must be completed. Such research currently is in progress.

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[6] No matter what frequency is accepted as the boundary between those frequencies most dependent on time-of-arrival and those dependent on amplitude, the division point would shift upward in water by a factor based on the speed of sound through a liquid. Hence, the boundary would be above 6000 Hz in any case.

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Table 1. Percent of correct localization responses to each of the four stimuli by 17 subjects. All stimulus presentations were at 110 dB SPL; the diver was located at an ear depth of 40 feet.

	Stimulus				
Subject	250 Hz	1000 Hz	6000 Hz	Noise	Mean
1	40	52	76	68	59
2	72	52	32	68	56
3	64	36	64	44	52
4	56	52	52	48	52
5	56	48	40	56	50
6	72	48	28	36	46
7	44	52	24	56	44
8	60	20	12	84	44
9	40	52	32	48	43
10	64	36	28	40	42
11	44	40	28	52	41
12	68	16	16	64	41
13	40	24	40	56	40
14	44	28	20	56	37
15	36	40	24	44	36
16	36	36	28	40	35
17	24	28	24	32	27
Mean	50.6	38.8	33.4	52.5	43.8
Standard Deviation	14.0	11.9	16.3	12.9	

Table 2. Pooled correct responses for 17 subjects and four stimuli relating actual projector location to perceived location.

	Source				
Response	90°	*45°	0°	315°	270°
90°	44	23	10	4	2
45°	34	43	14	6	5
0°	15	20	39	18	12
315°	4	7	20	48	38
270°	3	5	17	24	43

*Column does not add to 100% due to rounding.

Table 3. Mean of correct responses by quadrant and with respect to sidedness. Data are precent correct levels for 17 subjects and four stimuli presented 25 times each from four positions each separated by 45°.

Stimuli	Quadrant Mean	Quadrant Range	Sidedness* Left	Sidedness* Right
250 Hz	87	76-98	82	76
1000 Hz	80	66-90	70	66
6000 Hz	74	68-82	64	64
Noise	90	72-96	90	85
Mean	83		76	73

*The 45° and 90° positions were to the right of the diver; the 270° and 315° to the left.

Figure 1. A view of USRD's field facility at Bugg Springs.

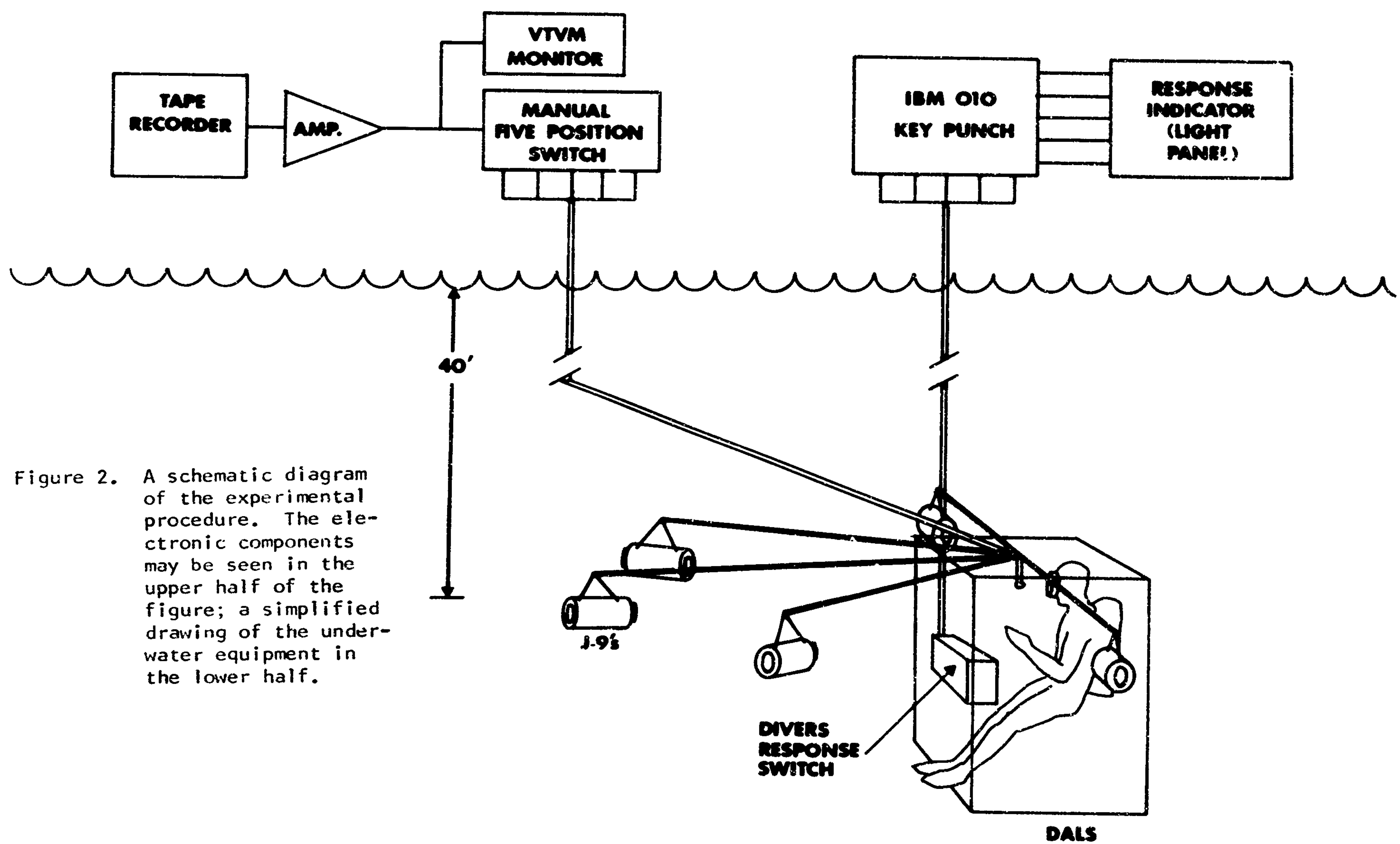

Figure 2. A schematic diagram of the experimental procedure. The electronic components may be seen in the upper half of the figure; a simplified drawing of the underwater equipment in the lower half.

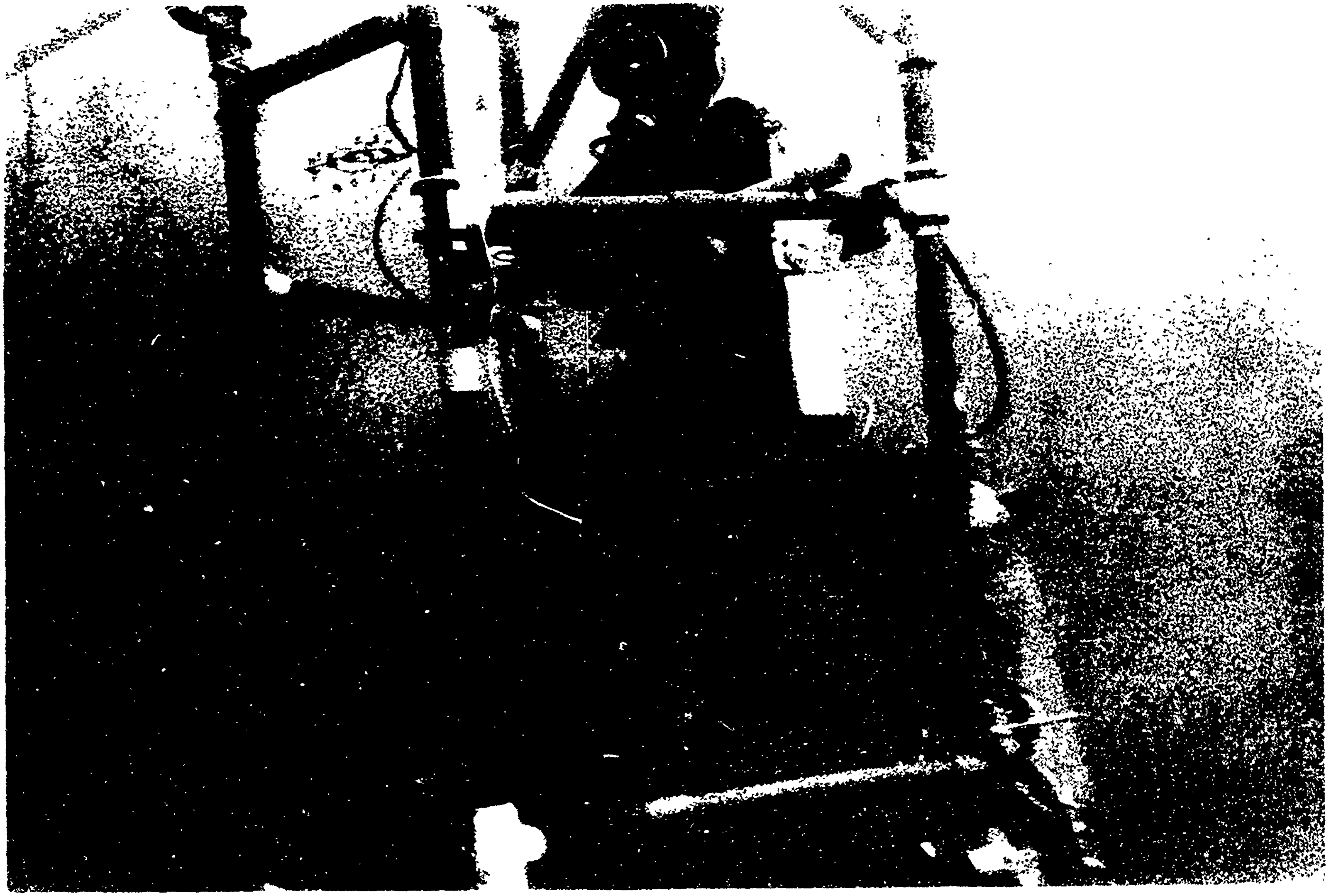

Figure 3. A photograph of one of the subjects actually in position. The arms of the DALS configuration are not shown; nor are the J-9 projectors.

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13. ABSTRACT

Theory and some empirical evidence are cited which predict that humans should exhibit little or no ability to localize sounds underwater; however, other evidence is presented also which seems to contradict this position. In order to provide relevant data on the issue, a pilot study was conducted with results suggesting that man can localize sounds underwater--at least to some degree. Accordingly, a series of experiments were carried out; the first is reported here. It utilized 17 divers who were free to move their heads but not their bodies in an underwater localization task. In order to allow precision in the experiment, a Diver Auditory Localization System (DALS) was developed. Based on previous structures employed in underwater communication research by the author, DALS consists of an open polyvinyl chloride (PVC) framework to which five 8.5-foot arms and other equipment can be attached. The five arms allow placement--at ear level--of underwater projectors at angles (to the diver) of 0^o, 45^o, 90^o, 270^o and 315^o. Subjects responded to four different signals--250, 1000, 6000 Hz sinusoids and thermal noise--at an SPL of 110 dB (approximately 40 dB re: underwater hearing thresholds) by means of a specially constructed five-position underwater switch coupled to an IBM key punch on the surface. The obtained correct mean scores were 1) 250 Hz: 51%; 2) 1 kHz: 39%; 3) 6 kHz: 33%; 4) Noise: 52% and 5) Overall: 44%. These data demonstrate that humans are capable of at least some primitive sound localization underwater; mechanisms are postulated that may explain this ability.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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Diver Localization						
Underwater Localization						
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(PAGE 2)

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