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Bureau of Medicine and Surgery, Navy Department
Research Work Unit: M4306.03-2020D.08

Released by:

J. E. Stark, CAPT MC USN
COMMANDING OFFICER
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SUMMARY PAGE

THE PROBLEM

To obtain frequency response curves on three types of microphones using a microphone previously calibrated under high ambient pressure by the reciprocity method.

FINDINGS

There is a generalized reduction in the linearity of a ceramic, cardioid and condenser microphone at frequencies above 3000 Hertz as ambient pressure increases to 19 ata in a helium-oxygen mixture. None of the three shelf-model microphones appears to be suitable for use with helium unscramblers that require a linear response to 10,000 Hertz. The ceramic microphone appeared to be the most consistent microphone during compression and decompression.

APPLICATION

The results of this study suggest that the reciprocity calibrated microphone may be used to evaluate other types of transducers in environments where no acoustic standard previously existed, specifically, in hyperbaric chambers. In addition, "off-the-shelf" microphones do not appear suitable for use in high pressures due to sensitivity and frequency response changes caused by such environments.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit M4306.03-2020DAC5 — Evaluation of Underwater Communications Systems for Navy Divers. The present report is number 8 on that work unit. It was approved for publication on 3 December 1971 and designated as Naval Submarine Medical Research Laboratory Report Number 690.

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ABSTRACT

The Navy's interest in deep diving has brought on the need to calibrate instruments and test equipment used for such dives. This study presents the result of changes in the frequency response characteristics of three microphones when pressurized to 19 ata in a helium-oxygen gas mixture. A microphone which was previously calibrated under the same conditions using the reciprocity technique (a technique by which no acoustic standard is necessary) provided the standard against which the other microphones were compared. The results suggest that "off-the-shelf" microphones do not maintain their sensitivity and frequency response when subjected to high ambient pressures. It is apparent that specially designed microphones which maintain a flat response under high ambient pressures are necessary in order to accommodate helium speech unscramblers. Of the three microphones observed, the ceramic microphone was most consistent with changes in ambient pressure and, furthermore, it was the only one of the three to return to its pre-dive electrical characteristic.

RESPONSE VARIATIONS OF THREE TYPES OF MICROPHONES PRESSURIZED TO 19 Ata

INTRODUCTION

The advancement of underwater communications has paralleled to some extent the advancement of helium speech unscramblers. However, while unscramblers have been available for several years and, to a degree, have increased speech intelligibility, the majority of communications is virtually unintelligible below 300 feet. Recent experimentation by Morrow [1] has indicated that the microphone used in the recording provides a major role in an unscrambler's overall value. Evidence by Flower [2] indicates that speech processed through unscramblers at 600 feet in a helium-oxygen atmosphere is still relatively low in intelligibility despite the advancements to the unscrambling system. Moreover, the results of Flower indicate that intelligibility scores differed as a function of the microphone being used to feed the unscrambler. While there has long been a need to examine the microphones used in connection with speech unscramblers, little data is available concerning changes in microphones in high pressure, helium-oxygen environments. The present study concerns itself with the operating characteristics of three different types of microphones in helium-oxygen mixtures. It was not the purpose to evaluate commercially available systems; rather, the purpose was to evaluate the operational characteristics of three types of microphones subjected to depths up to 600 feet. The chamber facilities and supervisor personnel of the Navy Experimental diving Unit, Washington Navy Yard, Wash., D.C., were made available to NavSubMedRschLab for these calibration tests.

Several investigators have already approached the problem of calibration of acoustic transducers under pressure (Colwell and Gibson, 1941[3]; White, 1955[4]; and Bauer and Torrick, 1966[5]; Sergeant and Duffy, 1970[6]; Sergeant and Murry, 1971[7]). In general, there is sufficient evidence to indicate that a degradation in the response of microphones and earphones is present under pressures greater than one ata relative to the response at standard atmospheric pressure. For example, White[4] found a 4.0-7.0 dB decrease in sensitivity from atmospheric pressure to 125 psia from a range of 125 to 9000 Hz, using a condenser microphone. White used the principle of reciprocity to obtain his measures which affords a primary calibration of the instrument without the necessity of a known reference. The reciprocity system appears suited to calibration under increased ambient pressure where no standard is available, since it does not depend on the acoustic output of a loudspeaker. Using this technique, one can obtain a reference and later use it for calibration of other microphones, earphones, and loudspeakers. The availability of a reciprocity calibrated transducer is the point of departure for the present study[7]. Subsequent to obtaining a reciprocity calibrated microphone under various pressures and gas mixtures, this study was undertaken to obtain the frequency response characteristics of three types of microphones; a piezoelectric (ceramic crystal), a ribbon (cardioid-type) and a condenser, and to compare the changes in their response characteristics with the changes in depth to 600 feet in a helium-oxygen environment.

PROCEDURE

In order to obtain meaningful data at increased atmospheric pressures, a reference transducer was first calibrated at various depths using the principle of reciprocity adopted for use in high pressure helium-oxygen environments[7]. In the study by Sergeant and Murry, a General Radio 1559-B Reciprocity Calibrator was used to calibrate a one-inch ceramic microphone. Calibration curves were obtained at the surface and at 100 feet increments to 600 feet; that is, 19 ata. The gas mixtures ranged from a 65-28-7 helium-nitrogen-oxygen mix at 100 feet to a 92.5-6-1.5 helium-nitrogen-oxygen mix at 600 feet. A calibration curve was obtained at each of these depths during the compression and decompression phases of the dive upon arrival at each depth. Subsequently, the reciprocity calibrated microphone was used as the reference for the calibration of a ribbon and a condenser microphone. The ribbon microphone was of the cardioid type; that is, one that operated on the pressure/gradient principles. These microphones were chosen on the basis that they are used or have been used in voice communication systems in hyperbaric chambers. Indeed, one of the instruments, the condenser microphone, has been repeatedly subjected to 600 and 1000 feet depths.

The reciprocity calibrated microphone and the test mikes were incorporated into the system shown in Figure 1 for the purpose of obtaining the frequency response of each microphone. Figure 1 is a block diagram of the microphone enclosure located inside the hyperbaric chamber and the test apparatus which was located outside of the chamber. The two microphones under test, the previously calibrated ceramic microphone, and a loudspeaker were located inside the enclosure. Fiberglass was used to line the enclosure in order to reduce the reverberation caused by the metal hull of the chamber. The loudspeaker, an eight-inch full range coaxial speaker, was driven by a General Radio 1304-B Audio generator whose frequency was verified by a Gen-

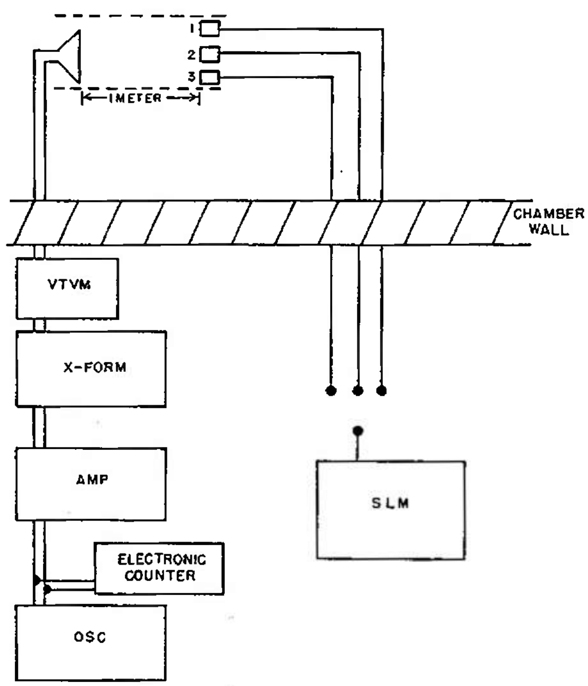

Figure 1. Block diagram of systems used to obtain the frequency responses on the microphones. One of the microphones is also the reciprocity calibrated microphone which is being used as the standard in this study.

eral Radio 1142-A Frequency Meter and whose output voltage to the speaker was verified by a Ballantine Model 643 AC Voltmeter. The responses of each microphone to the pure tone emitted from the speaker were measured by a General Radio 1551-C Sound Level Meter calibrated to read from a reference of .0002 dynes per square centimeter. All of the penetrations into and out of the chamber were continuous through the hull.

The calibration frequencies were 100, 250, 500, 800, 1000, 2000, 3000, 2500, 4000, 5000 and 6000 Hertz. The measures were taken upon arrival at the depth of interest. Since the response to all three microphones could not be measured simultaneously, there were undoubtedly some hysteresis effects associated with the calibration figures of each microphone which could not be directly determined. In order to have some assessment of the hysteresis effects, however, at 300 and 600 feet, readings were taken upon arrival and also one hour after arrival.

Prior to obtaining the final frequency response curves, it was necessary to correct the recorded values, due to the effect of the loudspeaker; that is, the normal deviations associated with the output of a loudspeaker in addition to the deviations associated with the added pressure in the chamber. These corrections were made using the data from the reciprocity calibrated microphone. Given a particular depth, the difference in the sound pressure levels at two frequencies obtained during the reciprocity calibration of the ceramic microphone, and the difference in the sound pressure levels in the two frequencies when the ceramic microphone was receiving a signal from the loudspeaker, and the real difference between the two frequencies from the indirect (loudspeaker) calibration system can be obtained. The difference in SPL for two frequencies will represent the real SPL difference for those two frequencies plus a value associated with the output of the loudspeaker. Knowing the sensitivities at the two frequencies when the microphone was reciprocity calibrated, any additional differences can be attributed to the output of the loudspeaker. Thus, any number of transducers may be calibrated under various conditions providing one of them has been absolutely calibrated. Since an enclosure was used to calibrate the microphones, some resonance effects might be reflected in the final frequency response curves. However, these effects must be considered minimal since the resonant frequency of the enclosure was approximately 115 Hertz and the first harmonic was more than 25 dB below the resonant frequency.

Upon obtaining the response curve for the ceramic microphone and subsequently the necessary corrections, frequency response curves for the other microphones were produced.

RESULTS

The results of this study are the frequency-response curves for all three microphones. The values at each frequency were corrected according to the criteria specified above and are presented in dB relative to the response of the individual microphone at 1000 Hertz at the surface. Since there was a certain amount of agreement from one depth to another, only the results at 0, 200, 400, and 600 feet will be discussed.

Figure 2 presents the frequency-response characteristics for the three transducers at the four stops during the descending phase of the dive. The response characteristics for the ceramic microphone indicate a general reduction in the sensitivity as depth increases until at 600 feet the sensitivity is about 20 dB below the sensitivity at the surface. The decrement in sensitivity appears somewhat uniform at the low frequencies while at the high frequencies, there is a rise in sensitivity with a peak at 5000 Hertz.

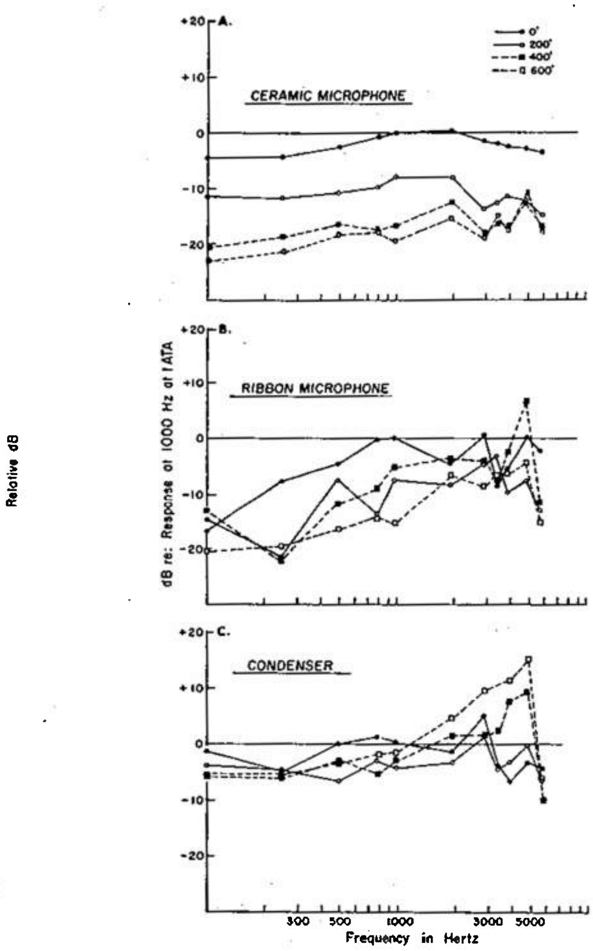

Figure 2. Frequency response characteristics of the ceramic (A), ribbon (B), and condenser (C) microphones at the start of the dive and at 200, 400 and 600 feet sea water equivalent during the descent phase of the dive.

The curves in Figures 2B and 2C are not as uniform. As can be seen for the ribbon microphone shown in Figure 2B, there are several apparent resonances and antiresonances in each of the curves suggesting that the effects due to pressurization and changes in the gas mixture are not predictable for this microphone that operates on a combination pressure/velocity principle. Additional consideration is given to the peaks and variations in these curves below.

The frequency-response characteristics for the condenser microphone shown in Figure 2C present somewhat of a different picture than those for the other two transducers. The sensitivity of the lower frequencies drops very little between the surface and the 600 feet depth while at the higher frequencies, there is a marked increase in sensitivity up to 5000 Hertz.

Figure 3 presents the frequency-response characteristics of the three transducers at the four stops during the descending phase of the dive. Upon examination of the curves in Figure 3A, it can be seen that the curves resemble those for each of the three microphones shown at the surface in Figure 2. While none of the microphones shows ideal characteristics for speech transmission, it must be remembered that they had previously been subjected to various depths for speech recording and they are standard microphones not built specifically for this particular environ-

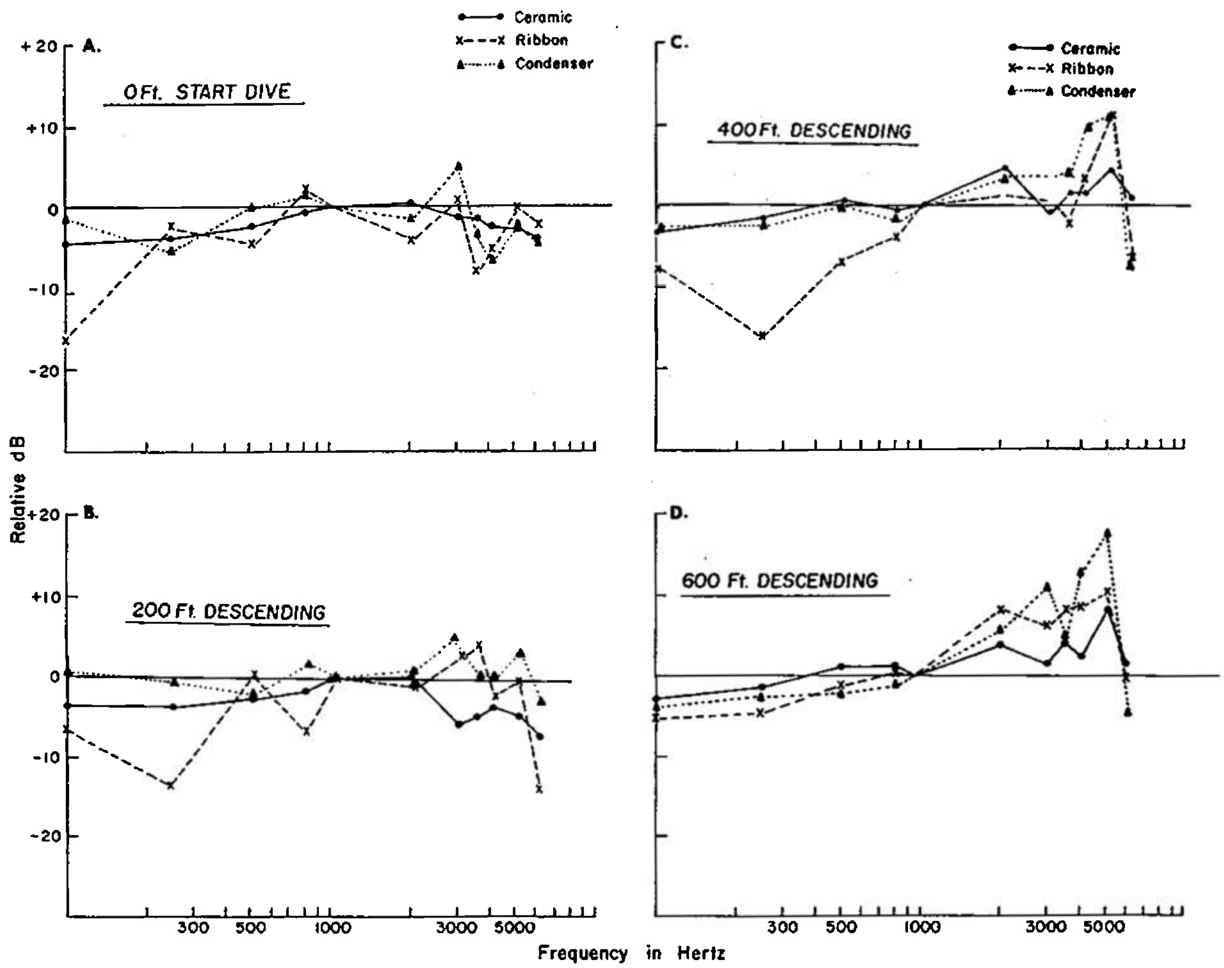

Figure 3. Relative responses of the three microphones during the descent phase. All readings are presented in dB relative to the response of the individual microphone at 1000 Hertz at the surface.

ment. The response curves at the surface provide a base line for comparisons at the increased depths. Figures 3B, 3C, and 3D show the frequency-response curves for the same three microphones at 200, 400, and 600 feet. As can be seen, the changes in the relative response curves are more predominant at the frequencies above 2000 Hertz. More specifically, up to 2000 Hertz there is a somewhat uniform curve for the ceramic and condenser microphones; the ribbon unit does not show agreement with the other two at any one depth except at 600 feet. Moreover, the ribbon unit does not agree with itself from depth to depth. The results shown in Figures 2 and 3 appear to indicate that an increase in the depth is associated with a relative increase in the sensitivity of the microphones between 3000 and 5000 Hertz. However, as one increases the ambient pressure, the three microphones show an overall general reduction in their sensitivity. The ceramic microphone showed the most uniformity from depth to depth, while the results of the ribbon unit lack consistency from depth to depth.

The results obtained during the ascent phase of the dive are shown in Figure 4. The calibration at 600 feet was begun one hour after arrival at depth. Note that there is a difference between the curves for the descending portion of the dive and those in this phase of the dive. More will be said about these changes later. During the ascending phase of the dive, it can be seen that as the depth decreases from 600 to 0 feet the microphones show changes similar to those that took place upon descent except, of course, in reverse order. The

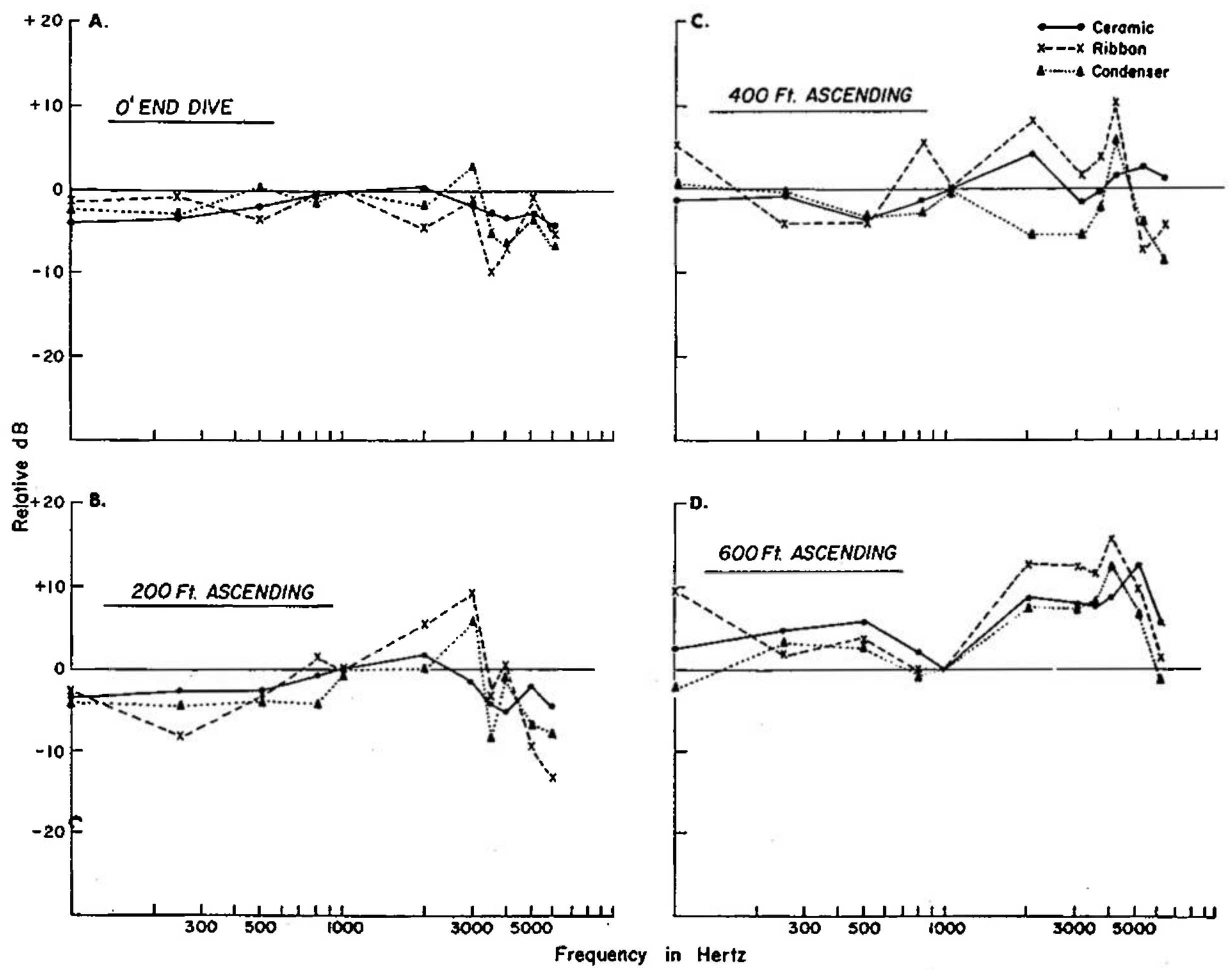

Figure 4. Relative responses of the three microphones during the ascent phase of the dive.

ceramic microphone continues to show the least change and the most uniform curve in sensitivity at the high frequencies while the ribbon microphone continues to show little stability from depth to depth and from one frequency to another at the same depth. Note also that at the greater depths there is a positive bias in the response at the frequencies above 2000 Hertz.

As mentioned earlier, it was expected that the measures obtained upon arrival at a depth might be affected due to the sudden change in the ambient pressure and that over a period of time at that depth, the sensitivity at any one frequency might change. Figure 5 shows the frequency-response curves at 600 feet upon arrival and one hour after arrival. Note in Figure 5B the elevated sensitivity at the low frequencies for all of the units. Also from Figure 5B, it can be seen that the shape of the curves at high frequencies is less variable and in fact each microphone has only one noticeable peak. Thus, it appears that the microphones may adapt to the environment after a period of time. Moreover, the adaptation seen at 600 feet would suggest that microphone transmission characteristics become better suited for speech after this initial period of adaptation. Similar results on this adaptation effect were obtained at 300 feet. Figure 6A shows the frequency-response curves upon arrival at 300 feet; Figure 6B shows the response curves 14 hours after arrival at 300 feet. The ceramic microphone showed little change after 14 hours from its original readings upon arrival. In fact, the curves for the ceramic microphone are within one dB of being identical throughout the spectrum.

In order to determine any significant long-term effects on the microphones for the overall dive, calibration curves were obtained on the three transducers 17 hours after ascent to the surface. Figure 7 shows these results and the comparisons for the two other conditions; prior to descent and immediately upon ascent, but with the hatch closed. As can be seen, the shapes of the two sets of curves in Figures 7A and 7B are approximately the same except at the lowest frequency. Notice, however, that in Figure 7C at 17 hours after ascent, the entire set of curves is lower. This is due in part, to the fact that as one ascends, the pressure change at 60 feet is approximately equivalent to the original surface pressure. Thus, the results obtained initially after the dive represent calibration in an atmosphere somewhat less than one atmosphere absolute. At 17 hours after the ascent, the pressure was the same as it was prior to the start of the dive. Only the ceramic microphone returned to within 2 dB at each frequency of its original frequency-response curve.

DISCUSSION

From the results presented above, it appears that there is a general decrease in the sensitivities of all microphones studied under the high pressure helium-oxygen mixture. Furthermore, noticeable changes occur in the linearity of the transducers especially at high frequencies. Finally, there was a cer-

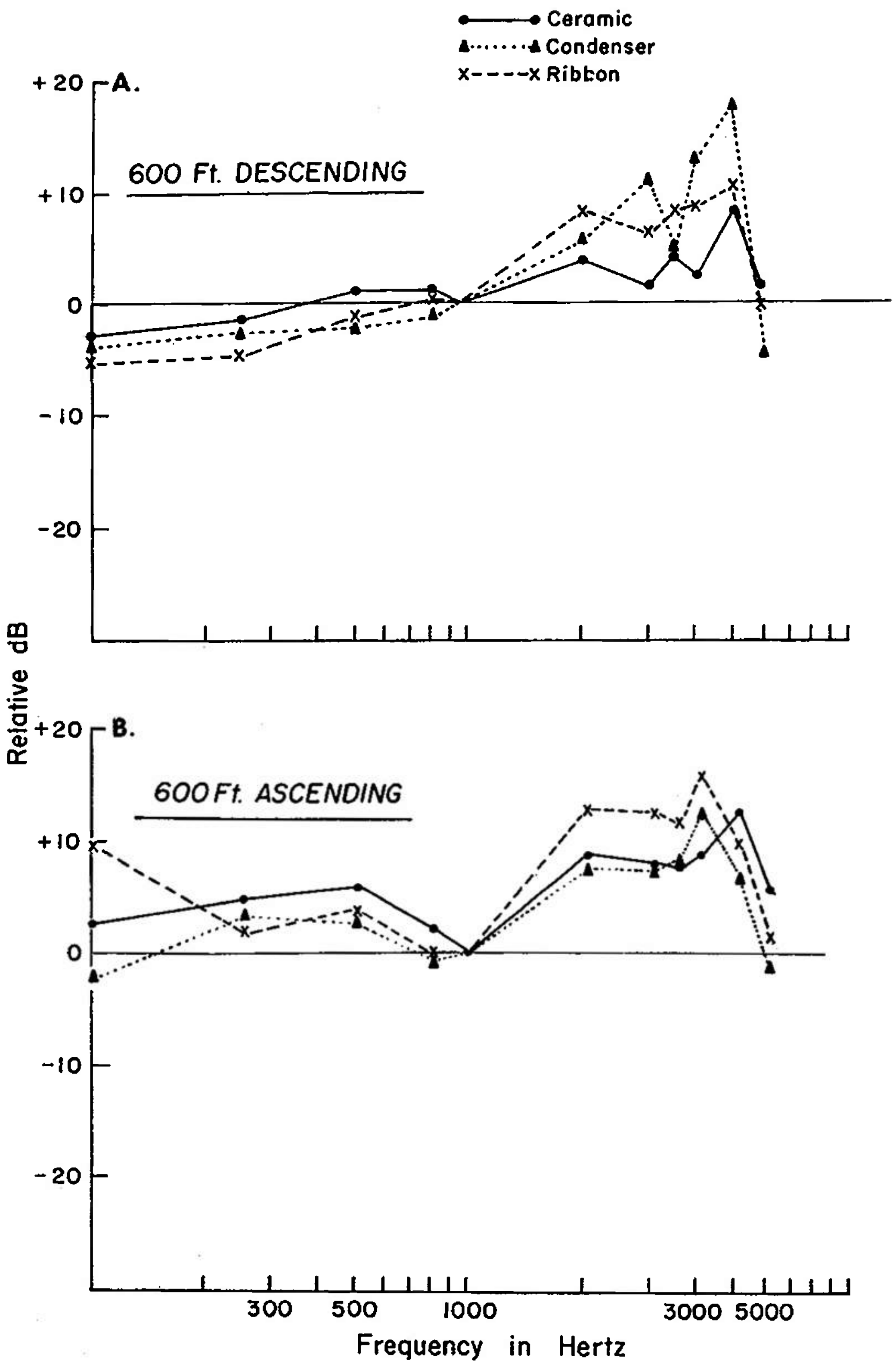

Figure 5. Changes in the relative responses of the three microphones immediately upon arriving at 600 feet and one hour after arriving at 600 feet.

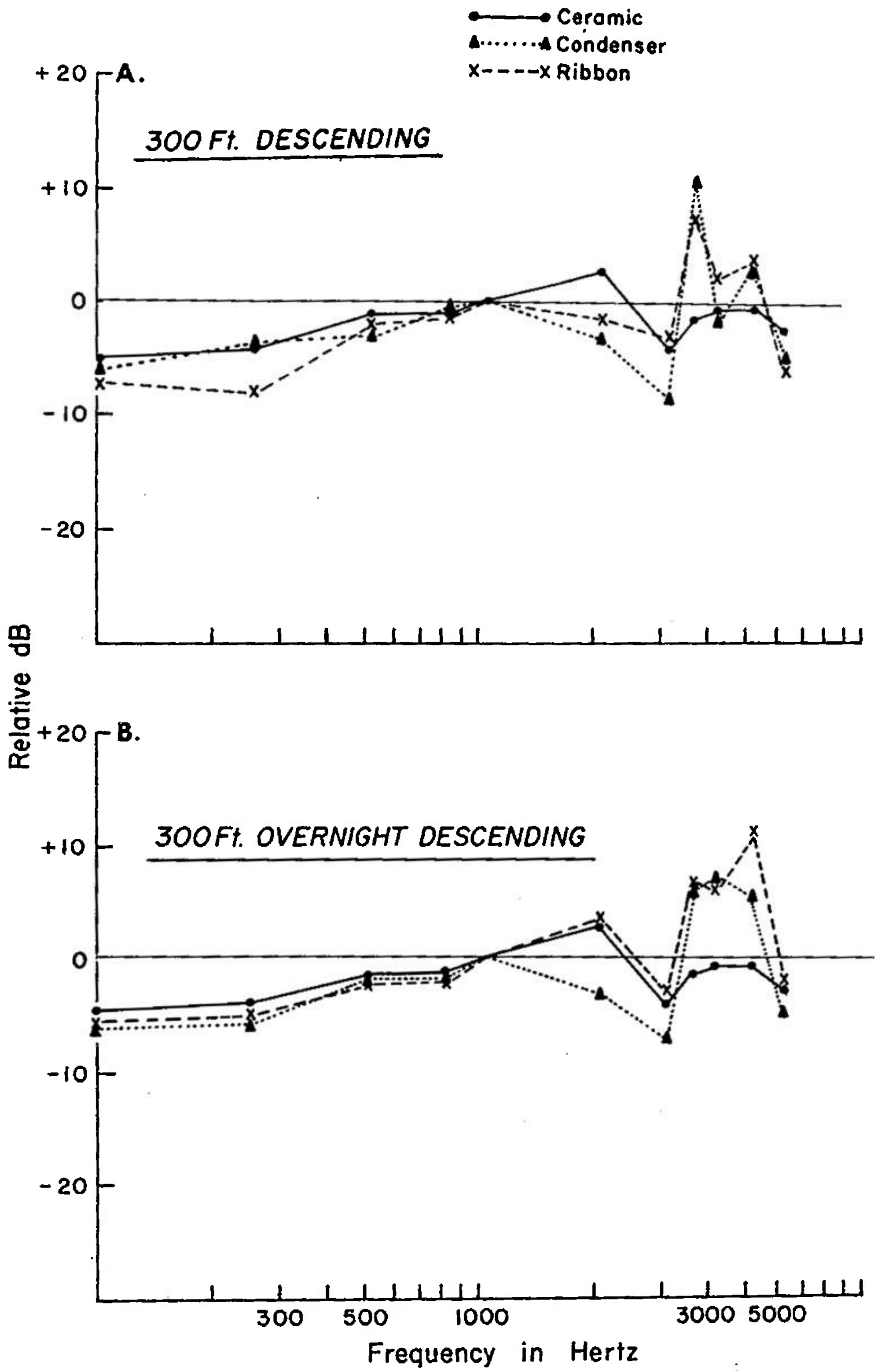

Figure 6. Changes in the relative responses of the three microphones at 300 feet during descent (A) and ascent (B).

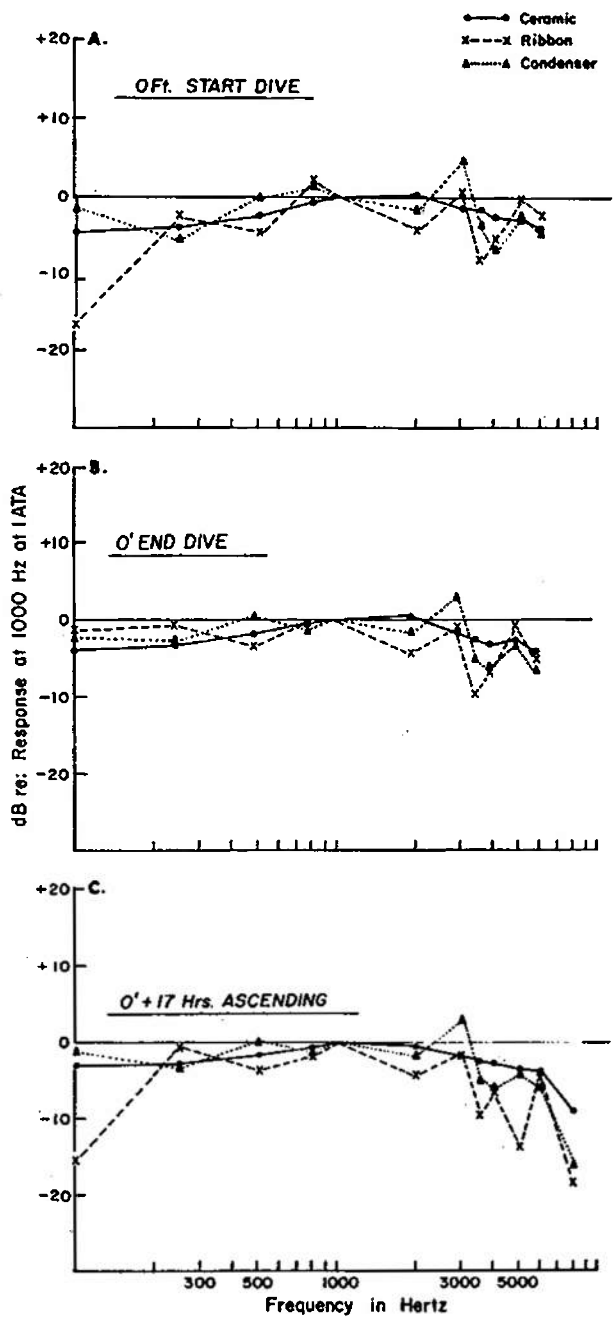

Figure 7. Comparison of the changes in the frequency response characteristics of the three microphones at the surface prior to the dive (A) immediately upon reaching the surface after the dive (B), and 17 hours post-dive (C).

tain amount of variability that existed from depth to depth at particular frequencies which limits generalization, especially for the ribbon microphone.

The ceramic microphone used in this experiment demonstrated the most consistent patterns during descent and ascent. There was approximately a 20 dB overall difference in sensitivity from the surface (1 ata) to 600 feet (19 ata) with a slight resonance peak appearing at 5000 Hertz at the 400 and 600 feet depths. Since this microphone was also reciprocity calibrated and produced the same curves at approximately the same sensitivities in two previous studies,[6,7] it would appear that such a microphone is well suited for repeated use to depths of 600 feet; however, the frequency response of this microphone may limit its use with helium-unscramblers.

The results of the ribbon microphone calibrations are not so clear, but there appear to be several reasons accounting for the variations observed. First of all, this microphone is a cardioid type of microphone operating partially on pressure and pressure-gradient principles. Thus, with this microphone, as the pressure and gas mixture change, the response must be expected to change. Since the diaphragm is connected mechanically to the transducer, there would tend to be an increase in the damping effects at high frequencies and consequently a lowering of the resonant frequency of the microphone. Not all of the changes of the ribbon microphone, however, result from varying pressures and gas mixtures. This appears to be especially true in the ascending stages. It appears that the microphone was damaged at the higher pressures resulting in spurious data points at various stops during ascent. Further evidence of this is shown in the results at 17 hours after ascent when the ribbon microphone, unlike the others, showed a curve quite different from its original predive curve.

With regard to the condenser microphone, the resonance effect seen at approximately 5000 Hertz appears to be the result of the increased pressure to an amount which overcomes the damping material used to extend the frequency response of the microphone. Therefore, instead of a resonance peak at approximately 12000 Hertz, the resonance effect at the high pressure conditions becomes apparent at 5000 Hertz.

The results presented above include some amount of variability as well as stability over the depths and frequencies involved. Nonetheless, the general conclusion of a reduction in sensitivity associated with increasing depths appears valid.

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