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**AUDITORY FEEDBACK AND HELIUM-SPEECH**

James F. Willott

and

Russell L. Sergeant

Bureau of Medicine and Surgery, Navy Department  
Research Work Unit MF12.524.004-9011D.01

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Gerald J. Duffner, CAPT MC USN  
COMMANDING OFFICER  
Naval Submarine Medical Center

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by

James F. Willott  
Connecticut College

and

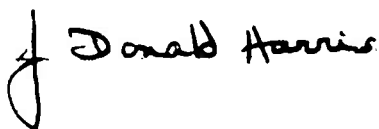
Russell L. Sergeant  
Naval Submarine Medical Center

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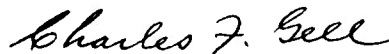
Principal Investigator  
Russell L. Sergeant, Ph.D.

Submitted by:



J. Donald Harris, Ph.D.  
Head, Auditory Research Branch

Reviewed and Approved by:




Charles F. Gell, M.D., D.Sc.  
Scientific Director

Reviewed and Approved by:



Joseph D. Bloom, CDR MC USN  
Director, SubMedResLab

Approved and Released by:



Gerald J. Duffner, CAPT MC USN  
COMMANDING OFFICER, SMC

## SUMMARY PAGE

### THE PROBLEM

To evaluate the effects upon speech produced in a helium-rich atmosphere when the talker's auditory feedback is masked by loud noise.

### FINDINGS

Mean intelligibility scores significantly improved about 10 percent for both speaking in air and in helium when loud noise interfered with the talker's ability to hear what he was saying. However, alterations made by the talker to improve his speech intelligibility when speaking in loud noise apparently were not related to either the acoustic character of vowels as revealed by spectrograms or long-term spectra of the voice.

### APPLICATION

Information contained in this report is useful to the design of communication systems which will improve production of speech by divers during deep-submergence.

### ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Work Unit MF12.524.004-9011D—Improving Skills in Listening, Body Balance and Orientation, and Verbal Communication Underwater. The present report is No. 1 on this Work Unit. It was approved for publication on 18 Sept. 1968, and designated as Submarine Medical Research Laboratory Report No. 544.

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## ABSTRACT

Acoustic and intelligibility analyses were made of speech from five talkers breathing air or a mixture of helium and oxygen, when their speech was or was not masked by loud noise of 95 decibels sound pressure level re .0002 microbar. Mean intelligibility scores, as determined from responses by 26 listeners, significantly improved about 10 percentage points for both air and helium conditions when noise interfered with a talker's ability to hear his own speech. The average long-term power spectra of speech in air and speech in the helium-mix did not differ to an appreciable degree as had been expected. However, sound spectrograms for the helium-speech revealed upward frequency shifts as typically reported. But neither the average spectra nor the spectrograms of helium-speech and speech in air showed significant differences between talking in noise versus talking in quiet. We conclude that alterations made to improve intelligibility while speaking in loud noise are not closely related to the acoustic variations analyzed in this investigation.

# AUDITORY FEEDBACK AND HELIUM-SPEECH

## I. INTRODUCTION

When deep sea divers are at work underwater, or in simulated underwater situations such as pressure chambers, they have difficulty communicating by voice with surface personnel and with other divers, due to the unusual sound of their speech while in these situations. There are two main reasons for the unusual sounding speech of deep sea divers. First, the increased pressure interferes with vocal production causing a nasal and crisp quality. Second, divers typically breathe a helium-rich mixture at great depths and this distorts the resonant characteristics of the vocal cavities producing a "Donald Duck" quality of speech.<sup>1</sup>

Fairbanks<sup>2</sup> theorized that the speaking system is a bioacoustic servosystem which monitors and controls its output by auditory means. Any interference with auditory feedback, or the ability to hear oneself talking, would be reflected in one's speech. It follows that secondary effects upon divers' speech may result from high ambient noise levels and poor hearing ability of men in pressure chambers or underwater.

## II. PURPOSE

The purpose of the present study was to investigate the effects of helium and masked auditory feedback upon speech in terms of the average power spectrum, sound spectrograph, and intelligibility. The power spectrum indicates the average acoustical power of speech at one cycle bandwidths along a frequency continuum for an extended period of time. The spectrograph shows the frequencies and intensities of formants, which are concentrations of acoustical energy of the speech signal, as a function of time.

The following predictions were proposed:

a. Comparison of sound spectrograms of speech at normal atmospheric pressures in air and in an 80-20 percent mixture of helium and oxygen reveal that formant frequencies for the helium condition are about one and one-half times those for air. It was proposed that this shift would be reflected by the long-

term average power spectrum with maximum energy shifted upward for the helium-speech.

b. If a person were to hear himself speaking abnormally, it is assumed that he would do something to make his speech sound more natural to himself. We predicted that the talkers in our study would show greater formant shifting in their helium-speech when auditory feedback was masked than they would when they had normal auditory feedback. This would indicate that when someone speaks while breathing helium-rich mixtures, he alters his vocal production in an attempt to overcome the undesirable changes caused by the helium.

c. Camp<sup>3</sup> found that there was an increase in intelligibility scores for speech produced in air when a loud masking noise was introduced to the talker's ears. This led us to predict that a similar increase in intelligibility would occur with helium-speech.

## III. METHOD

Samples of speech were obtained from five men who had normal hearing, according to typical audiometric testing. All recordings were made in an anechoic chamber at normal atmospheric pressure. Prior to recording, each man was trained to speak at a relatively constant vocal output while observing a VU-meter (A VU-meter measures Volume Units of Speech).

For acoustic analyses, the following sentence was recorded by each man under the four conditions which will be described later: "Tomorrow evening at this hour the famous physician Doctor J. O. Lee will speak to us about a matter of vital importance."

The Modified Rhyme Test<sup>4</sup> (MRT) was used to test intelligibility. In order to obtain a representative sampling of adult male speech, each man read one-fifth of the words in one MRT list. This was repeated until one list was available for each of the following four conditions:

Condition I: Talkers breathed air and had no restrictions imposed upon their hearing. Auditory feedback was normal.

Condition II: Air again was breathed, but random noise was introduced binaurally with earphones at a measured Sound Pressure Level (SPL) of 95 dB.

Condition III: Talkers breathed a mixture of 80 percent helium and 20 percent oxygen and random noise at 95 dB SPL was used to mask auditory feedback.

Condition IV: The helium-oxygen mixture was breathed and auditory feedback was normal.

Figure 1 summarizes the recording situation. The masking noise was produced by a General Radio Corporation Random Noise

approximated his comfortable speaking level for air with normal feedback. A carrier phrase was used with the test words. The microphone was an Altec 633A positioned six inches directly in front of the lips at a 90° angle. Speech was recorded on Channel One of an Ampex 300-2 Tape Recorder.

A separate tape-loop was made for each "J. O. Lee" sentence as spoken by each talker under each of the four conditions under study. These loops permitted continuous playback of a sentence on an Ampex PR-10 Tape Recorder. The recorder's output was passed through each of 21 third-octave filter pass-band settings, with midpoints ranging from

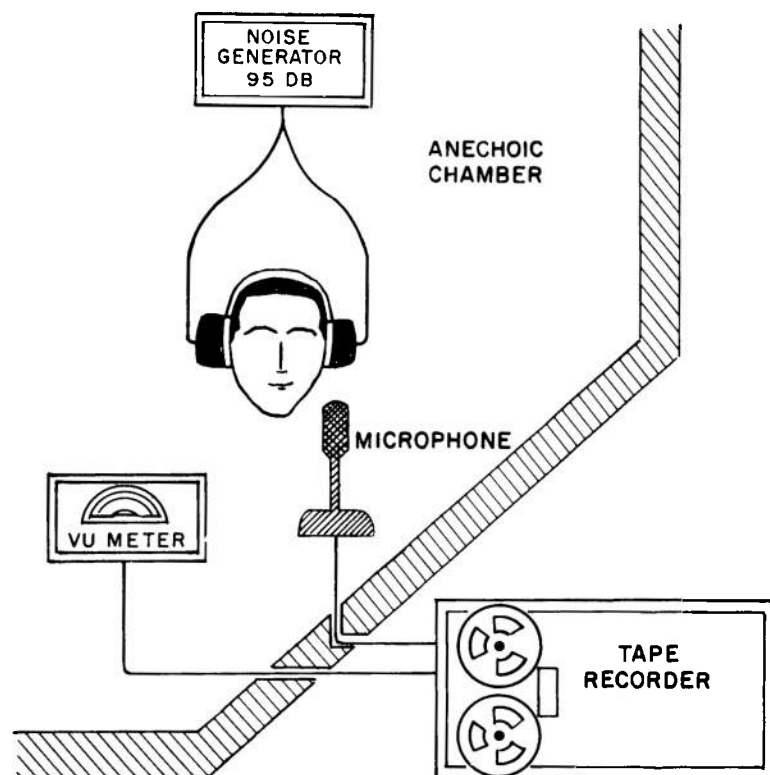


Figure 1.—Summary diagram of recording situation.

Generator and fed through an Altec amplifier to a set of Telephonics TDH-39 earphones in MX cushions. Since loud noise in the ears normally causes an increase in the intensity of the voice, each talker visually monitored the level of his speech on a Daven Co. VU-meter. Thus, each talker kept his vocal output at a relatively constant overall level which

125 Hertz (Hz) to 10 kiloHertz (kHz) on a Bruel and Kjaer Audio Frequency Spectrometer. The voltage of the resultant signal was measured with a Flow Corporation Model-TBM averaging root-mean-square (RMS) voltmeter. This provided the RMS voltage averaged over a period of 20 seconds for different passbands of speech produced under four conditions.

A Kay Electric Company Missile Data-Reduction Spectrograph, or "Missilizer," was used to produce spectrograms of the recorded sentences.

Recordings of the Modified Rhyme Test were presented to 26 normal-hearing Navy enlisted men in a group audio-testing room which contains 50 matched monaural headsets. The order of presentation on the tapes was by talker. The lists were presented monaurally at an average SPL of 70 dB in TDH-39 earphones embedded in Supra-aural cushions. This level was obtained by determining the average of speech peaks on a VU-meter for a list and recording a 1000 Hz calibration tone at that same level. Then, the output of the tone was set to measure 70 dB using a flat-plate coupler between headset and an SL meter. In order to maximize differences in intelligibility between conditions, random noise was mixed with the speech signal to produce a speech-to-noise ratio of minus 5 dB.

Listeners responded on answer sheets containing 6-word multiple choice blocks as described by House, et al.<sup>4</sup> Intelligibility was defined as the percent correct responses.

#### IV. RESULTS AND DISCUSSION

Two operations were performed to produce the average power spectrum. First, the values found at each filter band were converted to voltage in decibels relative to the unfiltered speech signal. This gave the power at each third-octave band of speech re the overall level. Secondly, a linear conversion was made to transform the third-octave power spectrum to the more basic "Spectrum Level", which is the level that would be measured if our analyzer had an ideal response characteristic with a bandwidth of one cycle<sup>5</sup>.

Mean values were obtained for the Spectrum Levels of five speakers and a final long-term average power spectrum of speech was obtained for each condition. Figure 2 shows these mean (for subjects) average (across time) spectra for the four conditions (of masking and breathing mix). The ordinant is relative voltage level; the abscissa is frequency in Hz. On first observation, there

seems to be little evidence of formant shifting, except for frequencies lower than about 1200 Hz. We felt that some obscuring of the expected shift might be due to variability among speakers. Therefore, individual power spectra for the four conditions were observed for each talker. Figure 3, which is representative of the data obtained for the other talkers, shows the long-term average spectra from 300 to 1250 Hz for one talker. Note that the levels for air (solid lines) reach a maximum near 500 Hz while the levels for helium-speech (dash-lines) reach their maxima closer to 800 Hz. However, due to the general flatness of the spectra for these frequencies, the evidence of upward shift is slight though positive. The implication is that Spectrum Level is not a very sensitive measure for observing shifts in frequency caused by breathing gas mixtures containing high concentrations of helium.

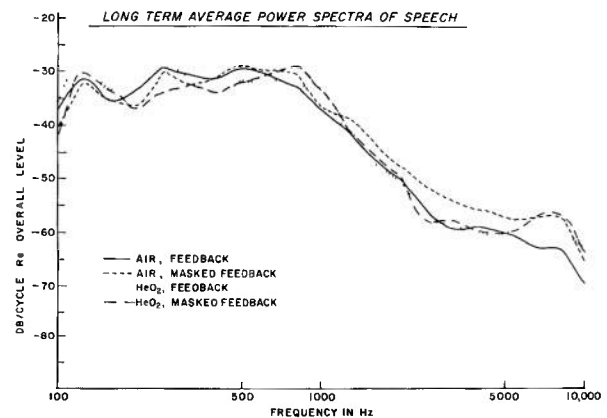


Figure 2.—Means of subjects' long-term average power spectra of speech in air and in HeO<sub>2</sub> with normal and with masked auditory feedback.

The second point of Figure 3 is to facilitate comparison between normal feedback conditions and masked auditory feedback. There is no significant difference between masked and unmasked conditions for either the speech in air (solid lines) or the helium-speech (dash-lines).

Spectrograms were made of the "J. O. Lee" sentences as produced by each speaker under the four conditions. Results obtained for the same subject whom we examined in

Figure 3 are presented in Figure 4. Spectrograms in the top line, I, are for air with normal feedback; the second line, II, is for air with the 95 dB masking noise; line III is for helium-speech with 95 dB noise present; and the bottom line, IV, is helium-speech with no noise. In support of the analyses of Spectrum Level, an upward shift in formant frequencies can be seen but differences due to masking the talker's auditory feedback with loud noise are not evident. Spectrograms for this subject are representative of the spectrograms obtained with the other four speakers regarding formant position.

The mean intelligibility scores of the 26 listeners for the four conditions studied are shown in Figure 5. In air, the introduction of masking noise produced an increase in mean intelligibility of 10.3 percent. A similar increase of 9.3 percent occurred when noise was added to the ears of speakers talking in helium. Both of these improvements to mean intelligibility are statistically significant beyond the .001 level of confidence, which supports our initial prediction based on Camp's investigation of speech produced in air in the presence of high level background noise. We conclude that interference with normal audi-

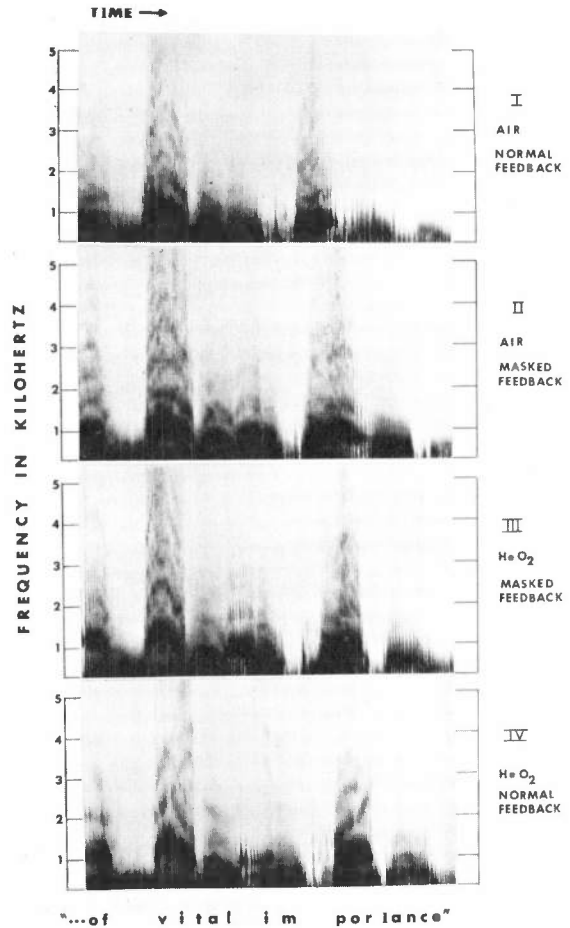


Figure 4.—Spectrograms of running speech in air and in HeO<sub>2</sub> with normal and with masked auditory feedback.

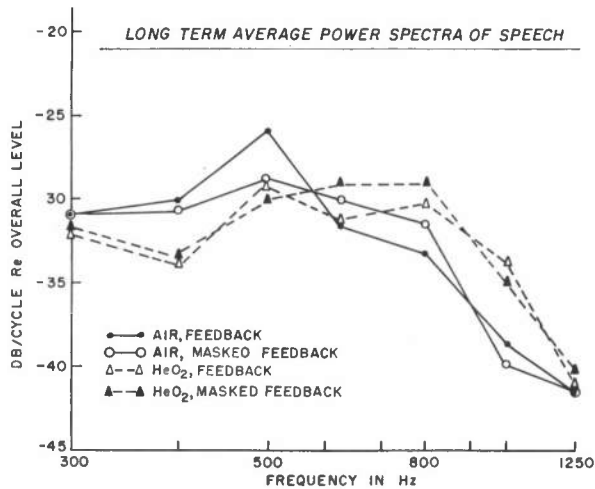


Figure 3.—Long-term average power spectra of speech from 300 to 1250 Hertz in air and in HeO<sub>2</sub> with normal and with masked auditory feedback.

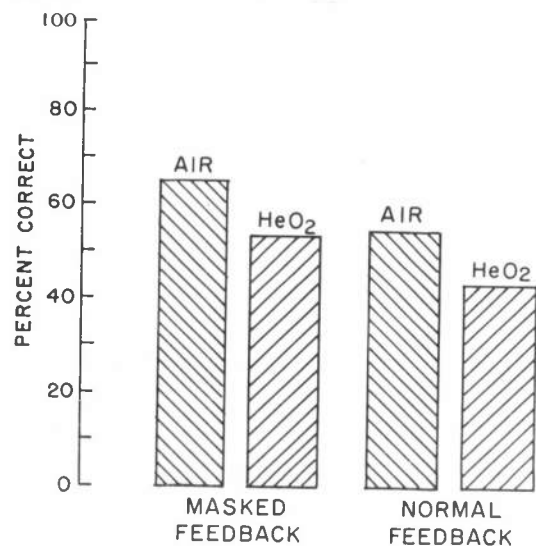


Figure 5. Mean intelligibility scores of speech in air and in HeO<sub>2</sub> with normal and with masked auditory feedback.



tory feedback causes a speaker to emphasize the preciseness of his speech in a beneficial manner. Apparently, however, this variation in vocal production related to neither the acoustical character of vowels as revealed by spectrograms, nor the long-term average Spectrum Level of the voice as observed here. Tolhurst<sup>6</sup> has reported that simple instructions to flyers about how to talk more clearly increased significantly their speech intelligibility. Any one of three instructions, "talk loudly", "articulate precisely" and "talk fast", improved speaker intelligibility. We believe a similar improvement would occur either with simple instructions or more formal voice training with speech produced in exotic gas mixtures under stressfull conditions common to various undersea operations.

## V. SUMMARY

The effects of auditory feedback upon production of helium-speech were evaluated. The long-term average spectra of speech did not reveal striking differences between speech in air and speech in the helium mix, as had been expected. Spectrograms of vowels revealed shifts upward for the helium-speech, as typically reported. However, neither the average spectra nor the spectrograms of helium-speech and speech in air showed significant differences between talking in noise versus talking in quiet. Mean intelligibility scores significantly improved about ten per cent for both air and helium conditions when noise interfered with a talker's ability to hear what he was saying. However, it appears that the alterations one makes to improve his speech intelligibility when speaking in the presence of loud noise are not closely related to either the acoustic character of vowels as revealed by spectrograms or to the long-term spectra of the voice.

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