U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

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THE INTELLIGIBILITY OF HELIUM-SPEECH AS A FUNCTION OF SPEECH-TO-NOISE RATIO

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9011D.02

Released by:

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SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 555

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SUMMARY PAGE

THE PROBLEM

To investigate the effects of noise interference upon the intelligibility of helium-speech and normal speech.

FINDINGS

Mean intelligibility scores significantly decreased about 2.3 percentage points per decibel (dB) increase in noise level for both helium-speech and normal speech. The helium-speech was approximately 10 percentage points less intelligible than speech in air when the speech-to-noise ratio was —5 dB.

APPLICATION

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

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. 2 on this Work Unit. It was approved for publication on 31 Oct 1968, and designated as Submarine Medical Research Laboratory Report No. 555.

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ABSTRACT

Three experiments compared the intelligibilities of helium-speech and normal speech when both were masked by loud noise. Recordings were made of five talkers reading intelligibility word-lists. Several panels of listeners heard these recordings masked by different levels of background noise. In Experiment I, a fatigue effect seemed at first to be present differentially for the helium-speech, suggesting that short-term auditory fatigue may occur with helium. However, Experiment II, designed to observe the effect on intelligibility of time during listening session that material was heard, refuted the notion of short-term fatigue effects. Experiment III incorporated results of the first two experiments to evaluate the effect of introducing varied levels of noise upon intelligibility of helium-speech and normal speech when order of presentation of gas-mix was minimized. The helium-speech and speech in air were equally intelligible both in the presence of loud noise and in the presence of low level noise. However, helium-speech was approximately ten percentage points less intelligible than speech in air when the level of noise was close to the level of speech. We conclude from this study that the effects of adaptation and learning on the intelligibility of helium-speech should be investigated further.

THE INTELLIGIBILITY OF HELIUM-SPEECH AS A FUNCTION OF SPEECH-TO-NOISE RATIO

I. INTRODUCTION

In the early days of diving, an air mix was used to breathe, even at fairly great depths. It was discovered that as pressure increased, nitrogen narcosis developed, which produced a drunken-like disorganized behavior. Since any loss of rationality in the underwater environment is potentially dangerous, the nitrogen content of air was replaced with helium. However, while the problem of narcosis was effectively solved in this way, helium introduced its own peculiar distortions which hindered verbal communications. The subjective sound of the voice produced in helium was altered due to an upward shift in formant frequencies, and there was a concurrent decrease in intelligibility. At extreme depths, almost all intelligibility was lost because the helium-distortion of speech was added to distortions caused by increased pressures, extraneous noise, and poor communication components.

Deep sea divers today commonly breathe mixtures rich in helium, with accompanying deleterious changes in vocal quality. But although helium-speech sounds unusual, it is readily intelligible when produced at normal atmospheric pressure and heard under quiet listening conditions. However, substantial disagreement and lack of information exists concerning more specific relationships between helium-speech and normal speech. For example, we do not know the relative effects of noise interference upon the intelligibility of helium-speech.

II. MAJOR PURPOSE

Three experiments comprising the present study compared intelligibilities of helium-speech and normal speech, both heard in the presence of loud noise. In Experiment I, listeners heard either normal speech followed by helium-speech, or the reverse, under varying conditions of speech-to-noise ratio (S/N). Since results suggested possible fatigue or some other type of adaptation to helium-speech during the time of testing, Experiment II investigated the simple effect of inserting the test items in a particular fashion in a one-hour total listening session. Experiment III incorporated results of the first two experiments in an attempt to evaluate further the effect of introducing varied levels of noise upon intelligibility of helium speech and normal speech when order of presentation of gas mix was minimized.

III. PROCEDURES

A. General.

Intelligibility tests were constructed by tape recording words of the Modified Rhyme Test (MRT)[1] as read aloud by five adult male talkers. All talkers were equally represented on each of ten 50-word lists, five lists being spoken after breathing an 80-20% mixture of helium-oxygen and five lists after breathing air. The talkers attempted to maintain a constant level of vocal output by observing a VU-meter during recording sessions. Later a General Radio Graphic Level Recorder was used to determine the mean intensity level of words comprising each list. A 1-kilohertz (kHz) tone was placed at the beginning of test lists. Stimulus tapes were heard by subjects in a group listening room which contains 50 matched Telephonics TDH-39 earphones embedded in Willson supra-aural muffs. A flat-plate coupler and a General Radio S-L Meter were used in conjunction with the 1-kHz calibration tones to produce mean speech levels of 60 decibels (dB) sound pressure level (SPL) and appropriate levels of noise at the listeners' ears. Speech was combined with the white noise output of a Grason-Stadler 901A Noise Generator after an attenuator regulated noise level to produce the desired S/N's. Listening panels were normal-hearing Naval enlisted men who had no previous experience listening to materials designed for testing the intelligibility of speech and who had never heard helium-speech.

B. Specific Experiments.

In Experiment I, the level of noise was varied to produce S/N's of +5, 0, —5, —10 and —15 dB. One panel of 20 listeners heard five lists of helium-speech followed by five lists of speech produced in air. A second panel of 20 men heard the air-material first and then the helium-speech. An analysis of variance of intelligibility scores was performed to evaluate effects of gas mixtures breathed, S/N, and two orders of listening.

In Experiment II, the five air and five helium lists were alternated during presentation, i.e., air, helium, air, helium, etc. This was done to enable more precise examination of the effect upon intelligibility of the time during a one-hour listening session that material was heard. Noise was introduced to produce a constant S/N of —5 dB. A panel of 45 listeners heard this test material.

In Experiment III, six lists were arranged for presentation into three pairs, each having a list in air followed by one in helium. The first pair was presented at +5 dB S/N, the next at 0 dB S/N, and the final pair at —15 dB S/N.

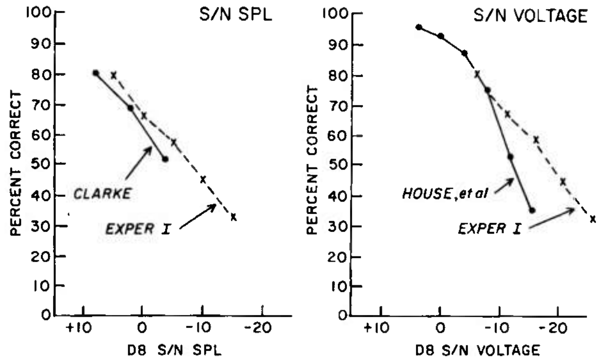

Fig. 1. Intelligibility of speech in air as a function of Speech-to-Noise ratio (S/N). (a) S/N determined from measures of Sound Pressure Level re .0002 dyne/cm². The dash-line derives from Experiment I of the present study. The solid line was taken from Ref. 2. (b) S/N determined from measures of voltage input to earphones. The dash-line comes from Experiment I. The solid line was taken from Ref. 1.

IV. RESULTS AND DISCUSSION

A. Technique to Obtain S/N.

Results obtained for the presentation of speech in air during Experiment I are shown in Figure 1. The ordinates indicate percent correct responses. The abscissae indicate S/N in terms of Sound Pressure Levels (SPL) in the supra-aural muffs in Figure 1(a) and in Figure 1(b) the voltage input to the multiple phone system. Notice the more negative S/N at the point of 50 percent intelligibility with voltage (1-12 dB) as contrasted with SPL (—8 dB). Similar data are plotted in Fig. 1(a) (see Clark[2]) and in Fig. 1(b) (see House, et al[1]). The sets of data show close agreement. Since the basic difference between the two techniques of obtaining S/N appears as a linear displacement along the abscissa, a nonsubstantive choice was made here to use S/N's based on SPL.

B. Experiment I.

Figure 2 summarizes data for conditions of air and helium. Mean intelligibility scores shown as a function of S/N ranged from 82% (normal speech at the most favorable S/N) to 22% (helium-speech under the least favorable S/N). The overall rate of deterioration of 2.3 percentage points per dB increase in noise (decrease in S/N) was the same for both helium and air. Intelligibility scores for the normal speech averaged almost 12% higher than those for the helium-speech under the same S/N whenever all air lists were presented before the helium lists. This difference did not occur when all helium lists were presented first.

TABLE I. Summary of Analysis of Variance (Experiment I).

Source	df	ms	F-Ratio
BETWEEN SUBJECTS	39	66	
A-Order	1	1440	48.1
Error (a)	38	30	
WITHIN SUBJECTS	360	84	
B-Gas Mix	1	815	91.5
AB	1	804	90.2
Error (b)	38	9	
C-S/N Ratio	4	6444	1676.5
AC	4	24	6.2
C x Ss	152	4	
BC	4	71	6.0
ABC	4	20	1.7
Error (bc)	152	12	
TOTAL	399		

Table I shows that the F-ratio obtained for S/N condition ($F = 1676.5$) is extremely large, as expected. Note also the highly significant F-ratios obtained for the other two main effects: B-Gas Mixture ($F=91.5$) and A-order of Listening to Gas Conditions ($F = 48.1$). Of special interest is the significant interaction ($F = 90.2$) between order of listening and type of gas the talkers breathed. This high variance could reflect a fatiguing or adapting effect for helium-

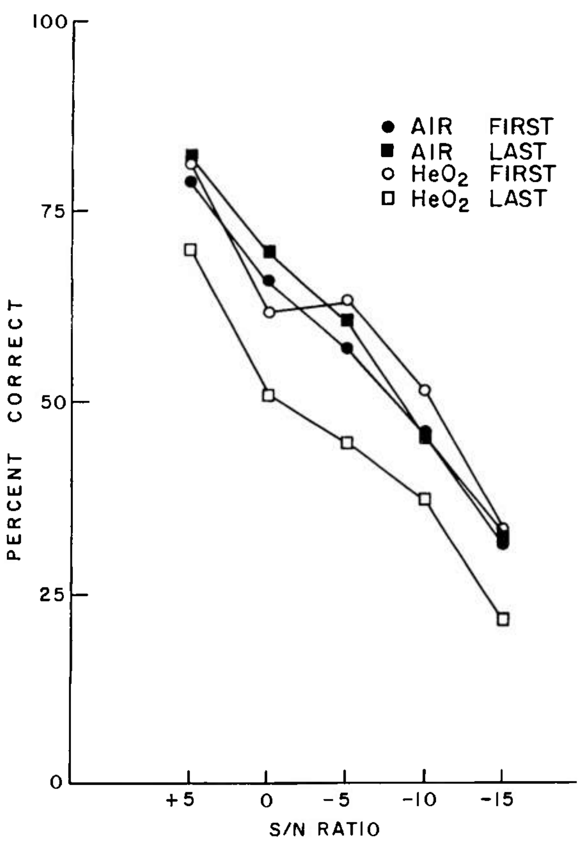

Fig. 2. Mean intelligibility scores of helium-speech and speech in air as a function speech-to-noise ratio (S/N). Parameters are gas condition (Helium mix and air) and which half hour (first or last) during a one hour testing session material was heard.

speech which was inherent in the testing situation. Note, however, that similar fatigue did not occur with **normal speech.** This suggests that when people are exposed to helium-speech for a period up to one hour, there is a reduction in receptive capability which is not present when they listen to speech produced in air.

C. Experiment II.

Here we examined more closely the effect on intelligibility of the time of listening during a test period lasting approximately one hour. In addition to the possibility of some type of short-term deterioration taking place during testing, there also could be increased listening capabilities due to long-term familiarity with the material to be heard. We know divers experienced in helium-diving have less difficulty understanding helium-speech than do novices. Since people in general are familiar with listening to normal speech produced in air, effects of becoming familiar with material might not show up during an air presentation, while such an effect would be active during presentation of the unfamiliar helium-speech.

Air lists were arranged to alternate with helium lists. An S/N of —5 dB was selected to provide scores in the neighborhood of 50%. The mean intelligibility scores ob-

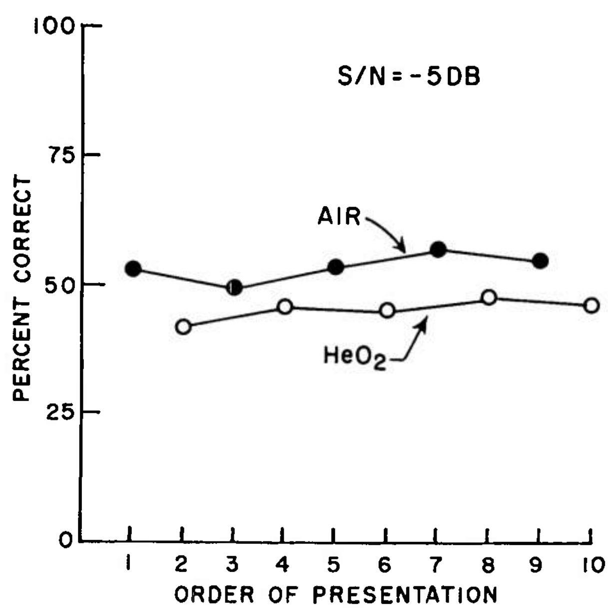

Fig. 3. Mean intelligibility scores of helium-speech and speech in air as a function of order of presentation during a one-hour testing session.

tained for each list are presented in Fig. 3. Unexpectedly, the helium-speech consistently was less intelligible than the speech in air. This contradicts results of Experiment I, which showed helium-speech and speech in air to be equally intelligible during the first half-hour of testing. Figure 3 reveals no deterioration in intelligibility. We conclude that some factor other than order of presentation or short-term adaptation within a one-hour listening session influenced the results of Experiment I. Indeed, we cannot explain why the helium material was as intelligible as it was when presented during the first half of the listening session of Experiment I.

D. **Experiment III.**

Experiment III provided another look at the effect of S/N on normal speech and helium-speech, this time with order effects minimized. Three noise levels (S/N's = +5, 0, and — 15 dB) were tested under each breathing mixture. Results are plotted in Fig. 4 along with the mean percentage points at an S/N of — 5 dB, obtained with air and helium in Experiment II. The 50% points of intelligibility occur at an S/N of — 3 dB for helium and — 7 dB for air. Near this area of 50% intelligibility, the difference between helium- and air-speech, as noted in Experiment II, approaches 10 percentage points, and, in agreement with data of Figure 2, rates of deterioration with increase in noise level in this area are similar. On the other hand, note that as noise increases from an S/N of +5 to — 5 dB, the rate of deterioration in intelligibility for helium-speech is more rapid than that for air. When noise levels are low (in the present study at 75% intelligibility and reported elsewhere for quiet listening), intelligibility scores are almost the same for both speaking conditions. At an S/N of — 15 dB the curves in Fig. 4 again approach each other. Ceiling and cellar effects inherent in the testing situation reduce differences between helium-speech and speech in air for high and low intelligibility scores. Where the test functions with maximum power of discrimination, the helium-speech was unquestionably less intelligible than that of normal speech. The question remains, is the relatively more rapid loss in intelligibility with decreasing S/N, for helium-speech, as observed from high scores to scores in the neighborhood of 50% caused by (1) weakness within the test or (2) the fact that helium-speech is actually more affected by increase of noise mask. The latter cause is more tenable.

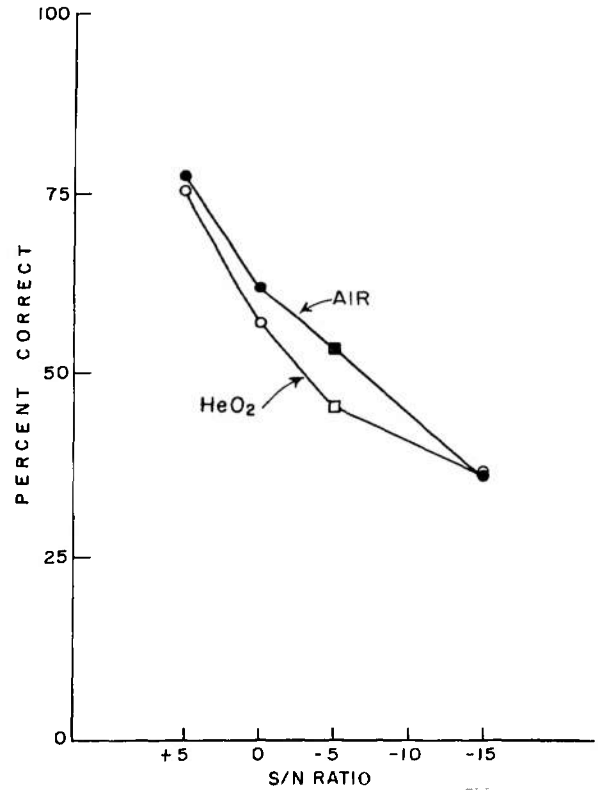

Fig. 4. **Combined results showing mean intelligibility scores of helium-speech and speech in air as a function of speech-to-noise ratio (S/N) with effects of order of presentation minimized. The two squares in the plot come from Experiment II, the circles from Experiment III.**

V. CONCLUSIONS

Noise-masked helium-speech and masked speech from talkers breathing air characteristically have equal intelligibilities when scores are very high or very low, i.e., in extremely high levels of noise or in quiet. But as S/N changes from +5 to — 5 dB, helium-speech more rapidly deteriorates than speech in air until there is a difference of approximately 10 percentage points in the area of 50% intelligibility. Effects of training may be important when listening to speech produced in deep-sea environments. In the present study such effects would show up only in the helium condition since members of listening panels were very familiar (well-trained) with speech in air but not with helium-speech. Experiment I suggested that effects of short-term fatigue may occur with helium, but Experiment II refutes this possibility. The short-term and long-term effects of fatigue, adaptation, and other kinds of learning upon helium-speech remain to be examined more closely.

VI. SUMMARY

Three experiments compared the intelligibilities of helium-speech and normal speech masked by loud noise. Recordings were made of five talkers reading intelligibility test lists. In Experiment I, these lists were presented to two panels of 20 listeners under speech-to-noise ratios from +5 to — 15 dB. Mean scores of intelligibility decreased significantly as noise level increased, and helium-speech was less intelligible than normal speech. A fatigue effect seemed to be present differentially for the helium-speech. In Experiment II, lists of air and helium words were altered during a one-hour test period. A panel of 45 listeners heard the material under a — 5 dB speech-to-noise condition. Results did not reveal the fatigue predicted from results of Experiment I. Consequently, the higher than expected intelligibility during the first half-hour of testing for Experiment I was questioned. Based on results of the first two experiments, Experiment III was designed to evaluate further the effects of various levels of noise on the intelligibility of speech when order of presentation of gas mix condition was balanced. The overall rate of drop in intelligibility for both types speech with S/N's from +5 to —15 dB was the same, namely, 2.3 percentage points per dB increase in noise level. Although the helium-speech and air-speech were equally intelligible both at an S/N of +5 and —15 dB, the helium-speech was approximately ten percentage points less intelligible than speech in air when S/N was —5 dB. The "short-term" and "long-term" effects of fatigue, learning, and other adapting effects upon helium-speech should be investigated further.

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13 ABSTRACT

Three experiments compared the intelligibilities of helium-speech and normal speech masked by loud noise. Recordings were made of 5 talkers reading intelligibility word lists. Several panels of listeners heard these recordings masked by different levels of background noise. In Experiment I, a fatigue effect seemed at first to be present differentially for the helium-speech, suggesting that short-term auditory fatigue may occur with helium. However, Experiment II, designed to observe the effect on intelligibility of time during listening session that material was heard, refuted the notion of short-term fatigue effects. Experiment III incorporated results of the first two experiments to evaluate the effect of introducing varied levels of noise upon intelligibility of helium-speech and normal speech when order of presentation of gas mix was minimized. Although the helium-speech and air-speech were equally intelligible at S/N's of +5 and -15 dB, the helium-speech was approximately 10 percentage points less intelligible than speech in air when S/N was -5 dB. In fact, over the S/N ratio range -5 to +5 dB, the overall change of intelligibility for both types of speech was the same, namely, 2.3 percentage points per dB change in noise level. We conclude from this study that the effects of adaptation and learning on the intelligibility of helium-speech should be investigated further.

14 KEY WORDS	LINK A		LINK B		LINK C	
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