Motor Speech Characteristics in Diving

H. Hollien, J.W. Hicks, Jr. and P. Hollien
Gainesville, USA

1. Introduction

The importance of good voice communication among underwater workers has been accentuated as advances in saturated diving techniques have occurred. However, since the HeO_2 atmosphere in deep diving exhibits different sound transmission characteristics than does normal air and, since the resultant effects (coupled with those of high ambient pressure) severely degrade speech intelligibility, voice communication at depth is substantially reduced – to the detriment of efficient work capability and safety. For some years now we have been carrying out basic experiments in an attempt to identify the specific speech changes that occur as a function of HeO_2/P. In this regard, we have tended to focus our efforts on vowel formant shifts, changes in speaking fundamental frequency and related speech features. Our data argue that the observed reduction in speech intelligibility at depth cannot be accounted for solely by HeO_2/P relationships; hence, we suggest that radically new perspectives are needed. First, we have developed a new predictive model, adding acoustic radiation through vowel tract boundaries and the neurophysiological effects of HPNS (high pressure nervous syndrome) to the established variables. Second, we also have modeled the approach that we believe best meets these new perspectives. In this (second) model, we suggest a combination of four research thrusts – focused on 1) electronic processors, 2) articulatory modification by divers, 3) a special lexicon and 4) trained/specialized decoders – as relevant/necessary to mitigate the problem.

The first of the two models cited above includes three (major) contributing elements: change in density of the breathing gas, change in high ambient pressure and the neurological effects of the high pressure nervous syndrome (HPNS). As is well known, the life support atmosphere in saturation diving typically consists of mixtures composed predominantly of helium plys oxygen and, in some cases, small percentages of nitrogen. The reason for replacing nitrogen with helium is that, as ambient pressure increases, nitrogen becomes first narcotic and then toxic – also the danger of decompression sickness (the bends) becomes severe. The effects of helium in this regard are not nearly as great: therefore, it is used to replace nitrogen at depth. Indeed, even the overall percentage of oxygen is reduced due to its toxicity as a function of pressure. Taken as a whole, the available data indicate that the introduction of helium causes an upward shift in the formant frequencies of vowels, but *more importantly*, all speech sounds are effected (Beil, 1962; Fant and Lindquist, 1968; Rothman and Hollien, 1972; Sergeant, 1963; Tanaka, et al. 1974). However, taken *alone*, this upward shift does not appear to materially affect speech intelligibility (Sergeant, 1963) – even when the talker is totally within the HeO_2 environment (Hollien and Hicks, 1982).

Changes, (i.e. great increases) in ambient pressure also appear to degrade speech. Among the distortions noted is a non-linear shift in the lower formant (F_1) resulting from changes in vocal tract resonance. Moreover, one of the first distortions encountered in hyperbaric (helium) speech is a perceived 'nasality' and Fant theorizes that this perception may be due to 'a shunting effect between the cavity walls and the environment'. Therefore, at high pressures, there is a reduction in the impedance mismatch between the gas mixture and the cavity wall, and this latter effect can be a cause of distortion. In general, we agree with this position. Radiation of acoustic energy through the oral/facial wall undoubtedly does increase in parallel with ambient pressure and, while this factor probably does not constitute the 'main cause' of speech degradation at depth, it surely is of substantial importance.

Finally, the hyperbaric environment also produces physiological and psychological changes in the diver; changes which ultimately affect speech production. An example of such a potential disruption is the high pressure nervous syndrome (HPNS). While physiologists have understood the principal hazards involved in deep diving (i.e. oxygen toxicity, hypothermia, narcotic effects of gases and the effects of a dense atmosphere on respiratory function) at least since the early 1959's, the effects of the hyperbaric environment on the central nervous system were not identified until somewhat later. HPNS appears to be a complex and variable phenomenon; functioning as a consequence of: 1) absolute pressure, 2) rate of pressure change (compression rate); 3) gas mixture used, 4) individual susceptibility and 5) interaction among these factors. The overall result of HPNS appears to be disruption of normal neuromuscular activity as well as symptoms such as tremor, muscle jerks, convulsions and, in some cases, dysarthria (Vaernes et al., 1982). Accordingly we theorize that HPNS will have a measureable effect on the neuro-motor control required for speech production. In a sense, the relationship between speech production and HPNS can be thought to parallel the effects of Parkinson's Disease, at least on a temporary basis. In Parkinson's there is a general 'breakdown' in neuromuscular control which is associated with impairments to speech (Canter, 1963, 1965a, 1965b; Logemann and Fisher, 1981; Netsell et al., 1974). We predict that such is the effect of HPNS on divers' communicative ability.

2. Procedure

A consideration of the above review should suggest that speech intelligibility is not materially degraded by deep diving in HeO_2 mixtures. That is, taken alone none of the three effects appear to be severe enough to disrupt speech very much. But is this really the case? Four major thrusts have been carried out recently in an attempt to specify the exact extent (and nature) of this reduction in message intelligibility. A summarization of these data may be found in Figure 1. The data are from four of our projects; they were carried out at: 1) Sealab (DSSP) and EDU (Hollien et al., 1973), 2) the Duke and Westinghouse facilities (Hollien and Hicks, unpublished), 3) the Institute for Environmental Medicine, University of Pennsylvania (Rotman et al., 1980) and 4) at the Norwegian Underwater Technology Center, Bergen, Norway (Hollien and Hicks, 1981 and unpublished). As can be seen from examination of the figure, it can be generalized that speech intelligibility is degraded with increases in HeO_2/P. Of course, these projects exhibit rather substantial differences in research methodology (microphones and calibration, talkers

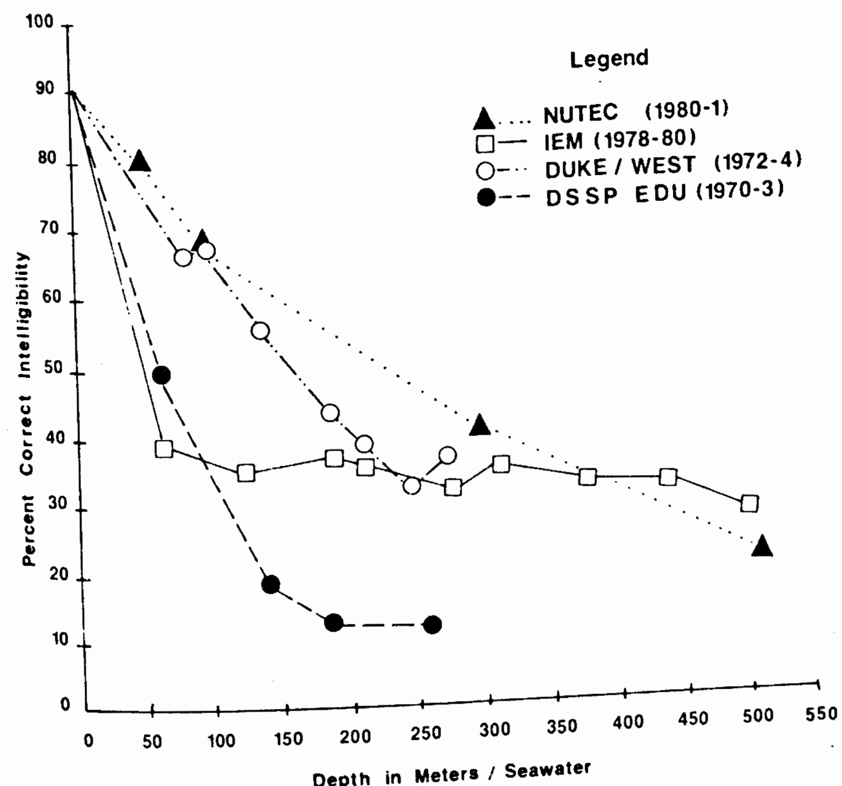

Figure 1. Summary figure of pooled data from several studies of speech intelligibility in the HeO_2/P environment.

differed in experience, noise levels varied and some speech was produced immediately after compression while other samples were obtained during decompression) and these factors tend to explain the differences among the curves. In any case, a good rule of thumb – relating speech intelligibility decrement to HeO_2/P level – appears to be that intelligibility level decreases approximately 10% per 50 meters for the first 100 meters, at a rate of about 10% per 100 meters for the next few hundred meters and finally at the rate of 3-5% per 100 m. So now it can be established that speech, indeed, is severely degraded at depth – and that it requires the addition of a third factor and the interactions among the three problem sources to account for the degradation. To be specific, what needs to be tested now are the physiological consequences of HPNS. One approach would be to assess the motor speech capabilities of saturated divers.

Research in this area was carried out at the Norwegian Underwater Technology Center's hyperbaric facility (Bergen, Norway). The dive was to 500 m and two of the three available aquanauts served as subjects.

Selection of a diadochokinetic test proved to be a problem. In our judgment, none of the available tests designed to assess the motor-speech function are better than marginally acceptable. Of course, development of such a test was not among the objectives of this research; hence we utilized the relatively informal tests proposed for, and already used in, research on motor-speech function. That is, we employed the Fletcher Time-by-Count Test of Diadochokinetic Syllable Rate (Fletcher, 1978) in this pilot study. Recording equipment included a calibrated B & K model 4166 condensor microphone (with a B & K model 2600 preamplifier) coupled to a calibrated laboratory quality tape recorder through a penetration tube in the wall of the chamber. In order to insure accuracy of timing, t-f-a spectrograms were made on a Voice Identification Model 700 unit and measurements were made with a 'time grid'.

3. Results

The results of this study are summarized in Table I, which provides summary data for the two subjects producing three single and one multiple phoneme as a function of depth. As can be seen there is a systematic reduction in the

Table I. Means of data for surface contrasted with means at depth. Values are number of productions as a function of time*

Condition	Single phonemes	Multiple phonemes
Surface (air)	5.65	1.92
Depth (HeO_2)	5.05	1.63
Difference	–0.53	–0.29

* Learning effects would bias toward improved scores at depth.

number of units the divers could produce as a function of increasing depth (i.e., increase in the proportion of helium in the environment, increases in ambient pressure and presumed decreases in motor coordination due to HPNS). When the data were converted to time required for a set number of repetitions, it was found that the two divers scored at the adolescent level at the surface and that their performance deteriorated 3-5 categories (to the norms for 9-year-old children) as a function of depth.

We should hasten to add that one variable affected our data. Prior to the project, we had no reason but to believe that the divers could carry out this task easily and that there would be no learning effect. Accordingly, we did not provide them with 'training' trials. Unfortunately, such was not the case and a very marked learning effect actually was observed – it was obvious both in subjects' hesitant behavior during the initial trials (at the surface) and in their comments about the task. Even with this variable operating to reduce the differences between surface and depth, a marked change was observed. We interpret these data to suggest that, indeed, HPNS was present when these divers spoke and it operated to degrade their speech. Further, the effects of the three sources of difficulty (HeO_2/P/HPNS) – even taken separately – begin to account for the substantial degradation of divers speech at depth. However, since these disruptions are mechanically induced, it may be possible to compensate for them, and increase speech intelligibility levels, by the application of training procedures suggested by relevant speech therapy. In any case, our theory that motor function is impaired at depth was supported – even though the neurological involvement did not appear to be as severe as with Parkinson's.

References

Beil, R.C. (1962). Frequency Analysis of Vowels Produced in a Helium-Rich Atmosphere. *J. Acoust. Soc. Amer.* **34**: 347-349.

Canter, G.J. (1963). Speech Characteristics of Patients with Parkinson's Diseases: I. Intensity, Pitch and Duration. *J. Speech Hear. Dis.* **28**: 221-229.

Canter, G.J. (1965*a*). Speech Characteristics of Patiens with Parkinson's Diseases: II. Physiological Support for Speech. *J. Speech Hear. Dis.* **30**: 44-49.

Canter, G.J. (1965*b*). Speech Characteristics of Patients with Parkinson's Diseases: III. Diadochokinesis and Overall Speech Adequacy. *J. Speech Hear. Dis.* **30**: 217-224.

Fant, G. and Lindquist, J. (1968). Pressure and Mixture Effects on Diver's Speech. *Quarterly Prog. Rept., Speech Trans. Lab.* Stockholm, 7-17.

Fletcher, S.G. (1978). *The Fletcher Time-By-Count Test of Diadochokinetic Syllable Rate.* Tigard, OR, C.C. Publications Inc.

Hollien, H. and Hicks, J.W., Je. (1981). Research on Hyperbaric Communication – A Progress Report. *IASCP/NUTEC-006/81*, 1-26 (Appendix A-C).

Hollien, H., Thompson, C. and Cannon, B. (1973). Speech Intelligibility as a Function of Ambient Pressure and HeO_2 Atmosphere. *Aerospace Med.* **44**: 249-253.

Logemann, J.A. and Fisher, H.B. (1981). Vocal Tract Control in Parkinson's Disease: Phonetic Feature Analysis of Misarticulations. *J. Speech Hear. Dis.* **46**: 348-352.

Netsell, R., Daniel, B. and Celesia, G.G. (1974). Acceleration and Weakness in Parkinson's Dysarthria. *J. Speech Hear. Dis.* **40**: 170-178.

Rothman, H.B., Gelfand, R., Hollien, H. and Lambertsen, C.J. (1980). Speech Intelligibility at High Helium-Oxygen Pressure. *Undersea Biomed. Res.* 7: 265-275.

Rothman, H.B. and Hollien, H. (1972). Phonetic Distortion in the HeO_2 Environment. *Proceed., Seventh Intern. Cong. Phonetic Sciences.* (A. Rigault and R. Charbonneau, Eds.), Mouton, The Hague, 589-598.

Sergeant, R.L. (1963). Speech During Respiration of a Mixture of Helium and Oxygen. *Aerospace Med.* **34**: 826-829.

Tanaka, R., Nakatsui, M. and Suzuki, J. (1974). Formant Frequency Shifts Under High Ambient Pressures. *J. Radio Res. Lab.* **2**: 261-267.

Vaernes, R., Bennett, P.B., Hammerborg, D., Ellertsen, B., Peterson, R.E. and Tonjum, S. (1982). Central Nervous System Reactions During Heliox and Trimix Dives to 31 ATA. *Undersea Biomed. Res.* **9**: 1-14.