SPEECH INTELLIGIBILITY IN DEEP DIVING

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ABSTRACT

Good communications are important in saturated diving. However, since heliox gas mixtures exhibit different sound transmission properties than normal air -- and high ambient pressures interact with them -- speech intelligibility tends to be degraded at depth. Attempts to improve communications here include the use of electronic processors and (in this case) modification of divers' speech. While it is known that divers can upgrade their speech at depth, little information is available about what they do to improve. Diver/talkers were trained to independently manipulate speech intensity, rate and FØ. Recordings were made at the surface and at 92.3m; intelligibility levels obtained via standardized listening sessions. The three vocal shifts that enhanced intelligibility were: low FØ, slow speech rate and high intensity.

1. INTRODUCTION

It must be conceded that divers are rather inefficient underseas workers [3]. Thermal effects, high pressures, weightlessness and especially poor communication, combine to limit a diver's ability to cope with the deep ocean environment and carry out reasonably complex tasks while doing so. In turn, divers' speech intelligibility is degraded primarily from exotic breathing gas mixtures, high ambient pressures, neural deficits, stress and hypothermia [6,8,11,12,15,17].

The four approaches which have been employed to restore the integrity of HeO2/P distorted speech can be found summarized in Figure 1. The use of trained decoders (D) is one remedial approach [10]; so is the use (C) of electronic devices [2,4,6,8, 14,16]. Third, attempts have been made to restructure language (B) as a compensation [1, 8]. However, while it must be noted that a totally new divers' lexicon probably would not be practical, appropriate data-bases are being collected and studied [13]. Finally, of the approaches portrayed in Figure 1, it is the articulatory characteristics (A) that may be both the easiest to

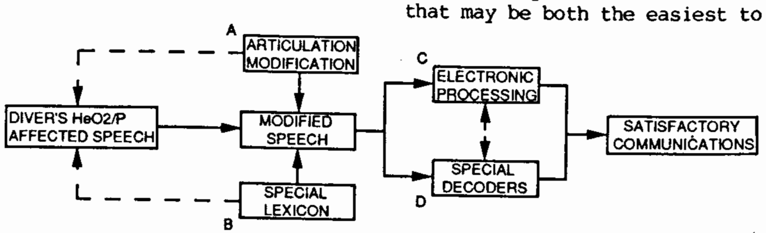

FIGURE 1

change and the most effective compensation for speech degradation in the HeO2/P milieu.

Figure 2 [7] will demonstrate that saturated divers experience severe reductions in communicative ability as a function of depth. The disparity here appears to be due to the effects of environment (reverberation, noise etc.), equipment, human variability and even HPNS (high pressure neural syndrome, 17). No simple solutions appear tenable; probably some combination of the four remedies will be necessary. While all require further study, the most critical need may be to determine how divers can modify their speech to become better communicators. This capability has not been addressed in the past.

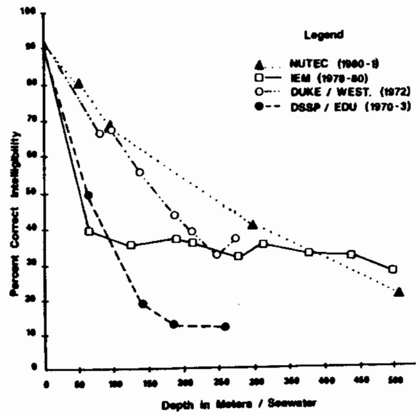

FIGURE 2

Finally, the speech changes which occur when divers attempt to communicate in HeO2/P environments have been documented to some degree. Briefly, these variations include nonlinear shifts in vowel formant structure [2,6] and (often) raised speaking fundamental frequency (FØ), at least on a behavioral basis [9, 12]. Other changes may or may not include shifts in VC ratios and the presence of nasal quality [7,8,12,15]. However, it should be stressed that these investigations have been focused on the (analysed) speech of diver/talkers -- when in environments which have varied extensively. Few investigators have attempted to study controlled/manipulated speech and these efforts have been confined primarily to shallow water [8].

2. PURPOSE

This study was conducted to investigate the effect of controlled articulatory modification on the intelligibility of divers' speech. To that end, diver/talkers were trained to separately alter, in turn, a single speech parameter while controlling all others.

3. METHOD

As stated, this investigation was carried out under highly controlled conditions with experienced divers who had completed a rigorous speech-control training program. It was conducted in the hyperbaric chambers located at the Westinghouse Ocean Research and Engineering facility, Annapolis, Maryland.

Subjects were twelve talker/divers (six males and six females) drawn from the University of Florida diver team. All were trained in phonetics and speech research, were certified/experienced divers and had served as subjects in previous experiments of this type. Moreover, to be included in the experiment, each had to demonstrate that he or she could produce the utterances with acceptable precision. Subjects were divided into equal groups; the first produced the required speech with normal sidetone, the second wore TDH-39 earphones into which was fed an 85 dB noise signal -- a procedure which essentially eliminated feedback. This approach permitted comparisons between talkers who could hear their speech well enough to attempt enhancement to those who could not.

All talkers read eight Griffith's [5] minimal contrast word lists in the seven different speech modes with the sequence counterbalanced to avoid order effects. The speaking modes were: 1) normal articulation, 2) "most intelligible", 3) high fundamental frequency, 4) low FØ, 5) slow speaking rate, 6) fast speaking rate and 7) high vocal intensity. As stated, subjects received extensive training in using each mode (except the first two, of course) while keeping the others constant. Fundamental frequecy was monitored using the IASCP Fundamental Frequency Indicator (FFI), during training sessions and the dive; intensity by means of a calibrated sound level meter, and rate by means of a stop watch. During the dive, flashcards were employed at chamber portholes to caution talkers who were drifting from these rigid protocols. All procedures were carried out twice for both teams: first at the surface in air and secondly at 92.3m (3ØØ fsw) in an environment consisting of 86% helium and 3% oxygen.

The recordings were made by means of calibrated, at depth, ElectroVoice 664 microphones coupled to Ampex 6Ø1 tape recorders (outside the chamber). It was concluded that, since less than 5-dB variations were obtained for frequencies up to nearly 1Ø kHz, the microphones were capable of functioning adequately at the experimental depth.

The experimental tape recordings were spliced, randomized and presented to groups of 12-15 listeners selected on the basis of (1) being native English speakers, (2) having normal hearing, and (3) being able to perform the listening task.

Before. their responses were evaluated, listeners were required to score at least 92% on a hearing screening test. Once the listening sessions were complete, the resulting data were tabled, analysed and statistical procedures applied.

4. RESULTS

One of the first contrasts was to compare the overall performance of the two groups. It was reasoned that, if training was effective, mean scores for the groups would show no differences. Indeed, they were found to be virtually identical; intelligibility levels at the surface slightly favored the group that spoke in quiet (95.3% vs. 92.8%). At depth, however, this difference was in favor of the group speaking in the high noise environment; here the difference was 2%. Further, no Lombard effect was observed in the speech of any of the talkers. These findings -- coupled with the expected male-female contrasts which were virtually identical at the surface and only slightly favored the men at depth -- served to demonstrate the robustness of the training.

Inspection of Figure 2 will reveal that a 3Ø-6Ø% reduction in speech intelligibility can be expected at depths around 1ØØm. The present data are consistent with that prediction. Even though the subjects employed in this research were trained, an overall degradation of nearly 3Ø% occurred at depth. Here the normal speaking condition (67.Ø%) again was found close to the overall mean and speech intelligibility was poorest for the two conditions of fast rate (61.Ø%) and high FØ (62.1%). The lowered FØ, however, resulted in a slightly better than average intelligibility level (69.Ø%) -- a finding that is not surprising since lower FØ also would tend to reduce (at least slightly) the raised vowel formants. The three speaking conditions that demonstrated the best overall performance involved those where best intelligibility was attempted (73.0%), speaking intensity was increased (72.0%) and speaking rate was slowed (70.6%). Other than the maximum intelligibility condition, the only relationship found statistically significant (ANOVA) was loudness (F=23.8, df 11, 132); this factor also was significant when a post hoc Duncan's multiple range test was applied. Even though the trends for the low intelligibility conditions (fast rate; high F0) were consistant across the noise conditions and gender, they were not statistically different from the others.

5. CONCLUSIONS

It is suggested that saturated divers attempting to communicate in the HeO2/P environment can improve their performance if they consciously attempt to do so. Helpful modifications include: 1) lowered fundamental frequency level, 2) reduced speech rate, 3) increased speech intensity and 4) attempted articulatory precision. Of course, it is conceded that these speech modifications might not be equally effective for all ambient pressure levels, gas mixtures and noise levels. Nonetheless, they did result in speech improvement under the conditions of this experiment.

6. REFERENCES

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