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PITCH AND ELOCUTION RATE OF DIVER'S SPEECH

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ABSTRACT

This paper aims to quantify the evolution of voice fundamental frequency and the slowing down of the speech tempo of 3 divers during the simulated dive HYDRA X at COMEX (Marseille, Nov-Dec 92). The average voice fundamental frequency which is higher in hyperbaric conditions than in free atmosphere conditions appears to be unrelated to breathing mixtures. The higher fundamental frequency shows a steady decrease along the saturation dive. Our study highlights a good stability of pitch frequency for the 2 divers who are in good condition and a bad stability for the other diver who lacks calmness and self confidence.
The slowing down of the speech tempo is very important (20% to 40%) during the first week of the dive, then the tempo steadily increases toward a standard value. The data related to the speech tempo is difficult to explain. One can think that it is correlated with some difficulties to breathe and to behavioural problems for the divers. The evolution of pitch frequency during the dive can also be related to psychological and behavioural problems.

1.INTRODUCTION

The adverse conditions of saturation dives causes significant changes in speech sounds of the divers. The most important effects have been pointed out for many years by many authors. They result mainly from the physical properties of breathing mixtures and more specially to sound celerity and density. Let us summarize briefly:

-an upward shift of the formant frequencies [1,2]. The linear shift yields the maximum expansion of the spectrum, proportional to the increase in sound velocity. The nonlinear shift results from the increase in gas density and modifies the lower formant frequencies.

-a broadening of the formants bandwith which at low frequencies is less than the formant shift.

-a significant damping of the signal enveloppe [3], this property is fundamental for the helium speech processing.

-a reduction of the voice intensity of unvoiced sounds relative to the intensity of voiced sounds [4].

The knowledge about these items allows enhancing of the intelligibility of speech by nonlinear frequency processing in speech unscramblers currently in use [5]. One can also notice the small signal to noise ratio in diving environments. Our study focuses on two others phenomena: the increase in pitch frequency and the slowing down of speech tempo. These two factors do not degrade the intelligibility of speech, consequently they are not incorporated in the most recently developped unscramblers, although techniques for the modification of the pitch [6] could be implemented. Such a progress would improve the naturalness of the speech and the identification of the speaker.

2.EARLY RESULTS

Increase in pitch frequency

Many published results report an increase in fundamental frequency in hyperbaric conditions [1, 7]. A study from Hollien [7] shows that the mean value of the fundamental frequency increases with the depth and that the scattering about the mean value is quite constant. Results from Fant [1] for an helium-nitrogen-oxygen mixture at depths from 60 m to 150 m shows for a diver an increase in pitch frequency from 124 Hz in air to 135 Hz at 60 m and 146 Hz at 150 m. Many early studies suggest that the pitch frequency does not vary as a function of the composition of the breathing mixture [4]. Other published data from Fant [2] shows that an increase in pressure in a given breathing mixture increases the pitch for some divers. Our results during the first experiment HYDRA [8] reveal that at a given depth a change in breathing mixture from heliox to hydrox lead to very small changes in pitch frequency despite very different physical properties. Many causes for the increase in pitch frequency have been suggested:

-a physical contraction of larynx muscles

-the diver attempts to improve the intelligibility of his speech

-the diver is looking for an easier way of speaking

-the intensity of speech is increased due to background noise levels in hyperbaric environment, the increase of intensity leads to an increased frequency (Lombard effect)

-the natural regulation of speech production can be altered (modification of sensations in vocal tract, modifications in hearing), these alterations can be related to the Fletcher effect.

Some of these modifications are due to physical properties of the environment, but others to volontary or unvolontary alterations of the divers's speech in response to the perception of their own speech. Consequently it is difficult to quantify these modifications because references in air at sea level change with time. Our study aims to quantify the evolution of pitch for the 3 divers during the very deep dive HYDRA X. Can the evolution be related to the progress of the dive and specially to the physiological and psychological condition of the divers? In atmospheric conditions increase in fundamental frequency can reveal a stress situation for the speaker. Experiments aiming to control the stress of aircraft pilots have been carried out and published [9].

Slowing of speech tempo

A slower speech tempo than in normal conditions is also characteristic of helium speech. Unfortunatly there are very few papers about that problem [1, 10] and none at such depths. The slowing of speech tempo analysed by Fant is reported to 38%. The author found that it is not correlated to the density of the mixture but possibly to the partial pressure of oxygen. This assumption has never been confirmed.

3.PROCEDURES

The analysed corpus is uttered by the 3 divers P1, P2, P3 during the experiment HYDRA X. It consists of 10 sentences phonetically balanced for depth from 10 m to 700 m. The 10 sentences are 5Khz sampled and computed by the speech software UNICE. The pitch frequency and the speech tempo are prosodic features, consequently they vary along the sentences. For each diver and for each depth the pitch frequency is the mean value of pitch for the voiced parts of the sentences. A mean value is computed for the entire corpus. The speech tempo is not computed, in order to simplify, the duration of the speech is directly evaluated and a mean value is carried out. The results for 14 depths (9 in compression stage and 5 in decompression stage) are reported on 2 figures. Figure 1 shows the evolution of pitch frequency and figure 2 the evolution of the mean duration of the sentences (function of the date). The corresponding values of depths and dates are summarized in the table below.

date	04/11	05/11	07/11	10/11	12/11
depth	010	200	400	475	525
date	14/11	16/11	17/11	20/11	21/11
depth	588	650	662	701	660
date	01/12	05/12	08/12	12/12	
depth	368	252	163	045	

4.RESULTS

Pitch evolution

The aim is to quantify the evolution of pitch frequency for the 3 divers during the experiment. The pitch references in air for the 3 divers are not determined in the same sentences. A complete study would imply recordings of the same sentences during the experiment, a week before and a week after. However mean values of pitch in air for every diver are available. The table below compares the results in hyperbaric conditions with the results in atmospheric conditions.

	Diver P1	Diver P2	Diver P3
air	115 Hz	105 Hz	110 Hz
hyp. compression	107 Hz	122 Hz	147 Hz
hyp. decompression	102 Hz	125 Hz	148 Hz
hyp. mean value	105 Hz	123 Hz	147 Hz

Previous results [1,2] show an increase of pitch frequency with the increase of depth. Our results show a mean value greater than in normal conditions : for diver P1 (+17%) and for diver P3 (+34%) but a slightly smaller value (-10%) for diver P1. A value smaller than in reference conditions is yet a very unusual phenomenon, our previous studies never have given such a result. Our mean values agree with those reported by Fant at very smaller depths. This clearly confirms that the pitch evolution is not directly tied to physical parameters of mixtures and depth. A more detailed evolution of pitch during the compression and decompression stage is shown in figure 1. The pitch frequency is sensitive to various disturbances, the begining of the compression stage, the change in mixtures (from heliox to hydrox and hydreliox to hydrox) but not necessarily in the same way for all divers. The study of the medical report of the dive suggests a link between this evolution and the physiological and psychological condition of the divers.

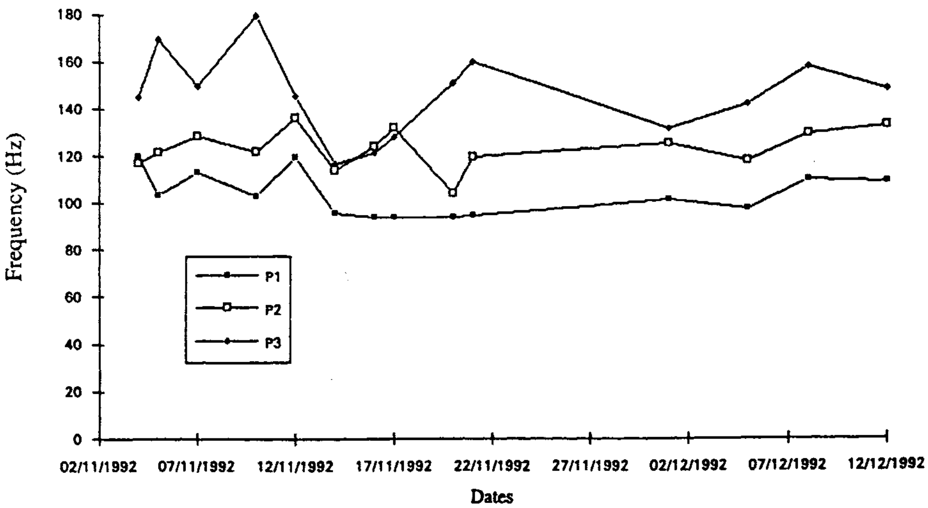

Fig.1 Evolution of pitch frequency

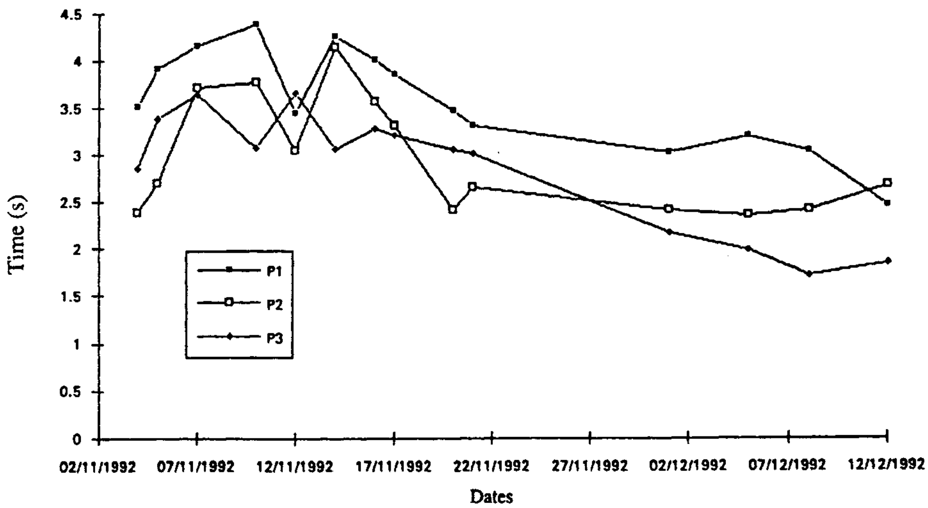

Fig.2 Mean duration of sentences

The 2 most efficient divers show good stability of their pitch with values not too far from their normal pitch, on the other hand the third diver shows very important variations far from his natural value. Important variations are observated for all divers on the 14/11 but no consistent explanation has been retained. Paradoxically the smaller value for P2 is reached for the maximal depth of 701m. The maximum pitch frequency of 180 Hz for P3 seems to be in a stress situation, for this diver in relatively bad condition the evolution of pitch is clearly tied to his problems. Two other results, that need confirmation because they rely only on few data, can be reported. Firstly the values for pitch frequencies when speaking naturally or when reading a text follow the same evolution during the dive. Secondly a study of the prosody in the 10 sentences shows for each diver the same prosody than in atmospheric conditions. This result is very important because it proves that the divers loose their absolute references for pitch but keep their instantaneous references. Despite the fact that the mean value of pitch frequency for each diver remains quite unchanged from compression stage to decompressicn stage (<5%) the variations within a word are very important. For

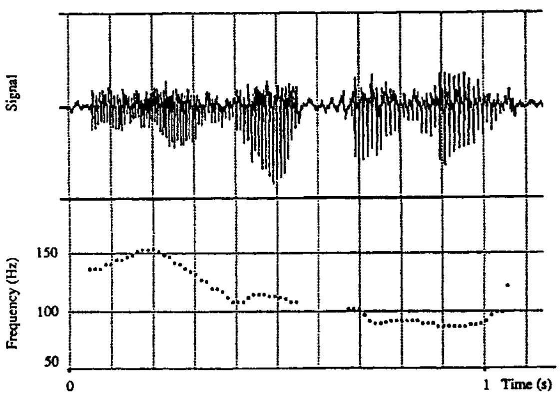

Fig.3 Signal and pitch evolution in the word "immediatement"

example in the word "immédiatement" (Figure 3) at a depth of 500 m, for a mean value of 114 Hz, the pitch varies from 88 Hz to 154 Hz.

modification in speech tempo

The speech tempo is quite slow for divers P1 and P3 at a small depth of 10 m, although the sentences are still very intelligible. One can think that it results from a real effort to speak clearly. The slowing down of the speech tempo is very important (25 to 60 % according to the diver) during the first week. During the dive the tempo increases steadily leading towards the values at the very begining of the dive. The assumption of Fant of a possible correlation with the partial pressure of oxygen is not confirmed. The results by Nakatsui [10] for a week duration dive at small depths present the same trends as our results. The variation is important at the begining of the dive, some reasons can be proposed -difficulties in the control of their speech production system, difficulties to articulate, adverse conditions, decrease of their effort to speak clearly- but along the dive with habituation they find again a normal tempo.

5.CONCLUSION

The pitch frequency and the speech tempo of divers do not use to be investigated, yet the analysis of these parameters can contribute to the evaluation of physical and physiological behaviour of divers, similar to information stemming from electroencephalogram and electrocardiogram. Enhanced speech unlike natural speech, does not allow the straight-forward detection of speaker's stress when listening. In hyperbaric environment the results of pitch computation could be displayed by the real-time speech unscramblers as an improved indicator of diver's behaviour to increase efficiency and safety in adverse conditions. Recordings of divers's speech during physiological tests and in working situations would be very useful to deepen this study.

REFERENCES

[1] G. Fant, J. Linqvist. *Pressure and gas mixture effects on diver's speech.* STL-QPSR-1 pp. 7-31, Royal Inst. Techn. Sweden, 1968.

[2] G. Fant, B. Sonesson. *Speech at high ambiant air-pressure.* STL-QPSR-2 pp. 9-21, Royal Inst. Techn. Sweden, 1964.

[3] J. Crestel, M. Guitton, V. Le Calvé, M. Corazza *Sur la quasi-stationnarité du filtre vocal en conditions hyperbares.* Colloque Gretsi pp. 753-756, 1991, Juan-Les-Pins.

[4] Brubaker R.S and Wurst J.W. *Spectrographic analysis of divers speech during decompression.* J.A.S.A 43 pp. 798-802, 1968.

[5] LL. Mendel, BW. Hamill, LJ. Crepeau, E. Fallon. *Speech intelligibility assessment in a helium environment.* J.A.S.A 97:1 pp. 628-636, Jan 1995.

[6] J. Suzuki and M. Nakatsui. *Translation of Helium Speech by Splicing of Autocorrelation Function.* J of the Radio Res. Labs, (Japan) vol 23 n° 111 pp. 229-234, July 1976.

[7] H. Hollien, W. Shearer, and J.W Hicks. *Voice fundamental frequency levels of divers in Helium-Oxygen speaking environment.* Undersea Biomedical Research 4(2) pp. 199 -207, June 1977.

[8] M. Guitton. *Contribution à l'amélioration de l'intelligibilité de la communication en plongée hyperbare.* Thèse de l'université de Rennes,1987.

[9] R. Ruiz et C. Legros. *Analyse de la voix de pilotes en situation de stress dans un simulateur de vol.* Premier Congrès Français d'acoustique pp. 527-530, avril 1990

[10] M. Nakatsui and J. Suzuki. Observation of Speech Parameters and their Daily Variation in a He-N2-O2 Mixture at a Depth of 30m. J. of the Radio Res. Labs (Japan), 18 pp. 221-225, 1971.