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Influence of Hyperbaric Heliox Environment at 31ATA on Microvibration and Electroencephalogram in Four Divers

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The simulated experiment of heliox dive to 31ATA in four subjects was performed for one month including the pressure holding for one week. In order to study the influence of hyperbaric environment on physical condition and level of consciousness, microvibration (MV) on thenar and eyelid and electroencephalogram (EEG) on T_4 and O_2 were measured at various atmosphere conditions. The power spectrum of MV and EEG were calculated: The peak frequency of power spectrum and the magnitude of power spectrum at the peak frequency were evaluated. The amplitude of MV increased after compression as compared with the value at pre-compression i.e., 1ATA, and the tendency was emphasized on eyelid MV at post-compression i.e., 1ATA, whereas the peak frequency of MV did not change significantly throughout the experiment. A remarkable hyperbaric effect was found in the evaluation of EEG peak frequency; The lowering of the peak frequency was recognized during the process of compression, pressure holding, and decompression. As the high pressure nervous syndrome (HPNS), especially during compression, was not recognized here, MV was not used as a detector of omen of HPNS, but the hyperbaric effect on skeletal muscle was found in ballistocardiogram component of MV due to the increase of the amplitude at post-compression. EEG denoted the lowering of level of consciousness during pressure holding, so that the result meant calling one's attention to the operation in hyperbaric environment of 31ATA.

Key words: Electroencephalogram (EEG), High Pressure Nervous Syndrome (HPNS), Hyperbaric Environment, Microvibration (MV).

INTRODUCTION

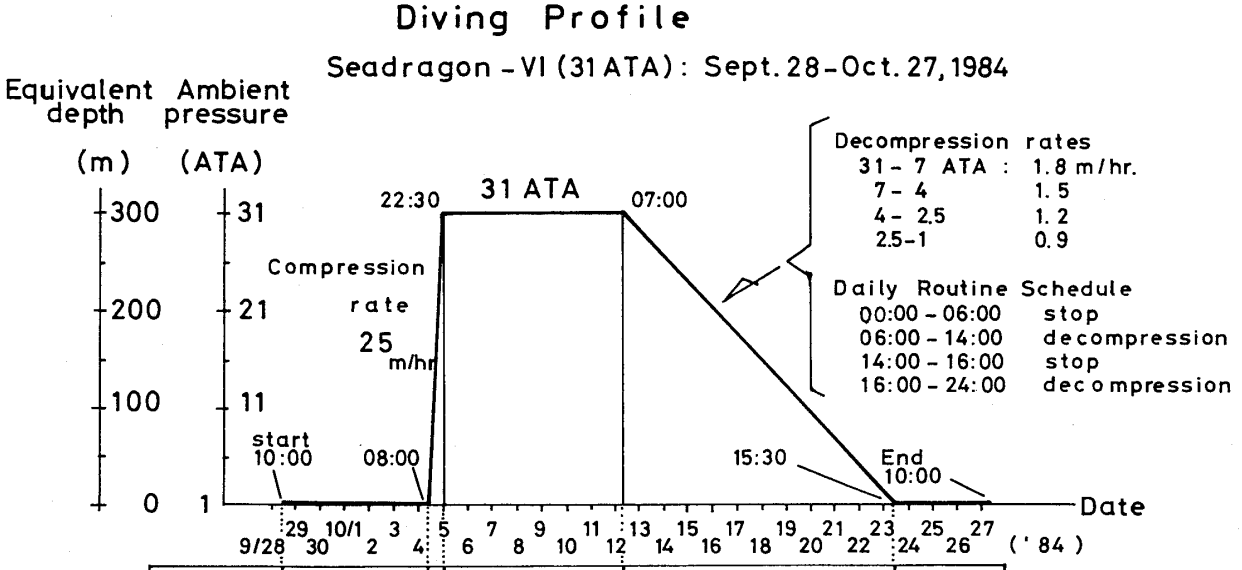
The simulated hyperbaric heliox dive (i.e., compression of mixed gas of He and O_2) to 31ATA (atmosphere absolute; 1ATA=ca. 1.013 bar) was performed in order to confirm human security for the operation in the bottom of open-sea around −300m which corresponded to the depth of continental shelf in the neighboring water of Japan. Such experiment till 62ATA have been tried by many authors (e.g., 37.5ATA, Fructus et al., 1969; 46ATA, Bennett and Towse, 1971; 62ATA, Rostain and Charpy, 1976). It is well known that the pressure more than about 21ATA causes high pressure nervous syndrome(HPNS) like the generation of physiological tremor and the lowering of attention and sensorimotor(Brauer et al., 1969; Fructus et al., 1969; Seki, 1979). The detection of HPNS and its prevention have been important problem to work

safely in the sea-bed. There are many studies of electroencephalogram(EEG) in hyperbaric environment (e.g., Fructus et al., 1969; Bennett and Towse, 1971; Corroiol et al., 1973; Rostain and Charpy, 1976; Rostain et al., 1983). Considerable papers concerning physiological tremor(i.e., postural tremor and intentional tremor) in the appearance of HPNS were published (e.g., Fructus et al., 1969; Bachrach and Bennett, 1973a; Bennett et al., 1974; Seki, 1979; Spencer et al., 1979; Rostain et al., 1980; Hugon et al., 1983; Seki et al., 1984). However, no study of microvibration(MV), which is the minor tremor on skin surface (Rohracher, 1955), in hyperbaric heliox dive has been made.

HPNS is generated not only at high pressure holding but also at compression (Seki, 1979). Therefore, in the present experiment, MV and EEG were employed to study the influence of various atmosphere conditions on motor nervous system and central nervous one. Especially, MV was expected to detect not the effect of HPNS but the omen, and EEG was used to check the lowering of level of consciousness.

METHODS

The experiment of hyperbaric environment was performed as 31ATA simulated human experimental project(Seadragon-VI) for one month(Sept. 28 to Oct. 27, 1984) at human diving simulator in Japan Marine Science and Technology Center. The number of days required for pre-compression, compression, pressure holding, decompression, and post-compression were 6,1,7,11, and 5 days, respectively. Hyperbaric heliox dive to 31ATA was operated by the schedule shown in Fig. 1. The compression rate was set up to be slow rate of 25m/hr., since high compression rate was apt to produce HPNS(e.g., 180m/hr., Fructus et al., 1969; 60-84m/hr., Hugon et al., 1983). The compression was interrupted for thirty minutes at 16ATA and for one hour at 21 and 26ATA. The partial pressure of oxygen gas(Po_2) used at pressure holding, 0.3ATA,



P_{O_2} (ATA)	0.21	0.30	0.30 ⟶ 0.21	0.21
P_{N_2} (ATA)	0.79	0.79	0.79	0.79
P_{He} (ATA)	0	29.91	29.91 ⟶ 0	0
T_a. (°C)	28.0	31.5	31.5 ⟶ 28.0	28.0
R.H(%)	60.0	60.0	60.0	60.0

Fig. 1. Diving profile in simulated heliox dive experiment.

was lower than the value of Rostain's group(i.e., 0.4ATA). The procedure of decompression was executed slowly according to the schedule. Four subjects entered into the simulator. Their age, stature, and body weight were as follows; A(32-years, 173.0cm, and 65.4kg), B(28years, 164.2cm, and 55.0kg), C(28years, 167.2cm, and 60.2kg), and D(33years, 167.2cm, and 62.2kg). Two subjects, A and B, were scientists, while other two, C and D, were professional divers.

The measurements of both MV and EEG are as follows: Subject lay on the bed (i.e., supine position), closing his eye, supinating his right forearm, and turning upward his right palm. One MV pickup (MT-3T, Nihon Kohden Co.) was sticked on the right thenar with single-sided Scotch tape, and other MV pickup was fixed on the right eyelid with double-sided Scotch tape. The acceleration of MV wave was measured. MV pickup produces electric voltage 1mV to the gravitational acceleration 0.01G. Therefore, MV was presented by electric voltage. The amplitude of MV in rest state gives generally a few mV. EEG was measured with disk type electrodes by the same procedure as Rostain and Charpy employed(1976). EEG measured between positions T_4 and O_2 was analyzed. MV and EEG for four subjects were measured simultaneously for six minutes a day (almost in the morning). The time constant and high cut frequency for both waves were 0.3sec and 30Hz, respectively.

The calculation of fast Fourier transform(FFT) of the data for every ten seconds epochs was carried out by the signal processor ATAC-450(Nihon Kohden Co.) and then the square root of power spectrum was displayed in the frequency range from 3 to 30Hz. In the calculation, sampling time and sampling point were taken to be 7.8msec and 256, so that one power spectrum required two seconds and the average of five power spectrum was obtained with the frequency precision of 0.5Hz. Since the value of peak frequency in the square root of power spectrum showed individual difference, in order to evaluate the influence of hyperbaric atmosphere on the peak frequency, the mean value of the peak frequency for each subject in pre-compression(i.e., 1ATA) for three days measured was used as control value, and the mean values for the other atmosphere conditions for each subject were evaluated by the percentage on the basis of the control value(i.e., 100%). As for the estimation of amplitude of MV and EEG, the square root value of power spectrum at the peak frequency was used. The procedure for the evaluation of amplitude was the same as that of the peak frequency.

RESULTS AND DISCUSSION

The peak frequencies in MV power spectrum on thenar and eyelid are shown in Fig. 2. The change of the peak frequency in the various atmosphere conditions for respective subjects did not indicate a uniform tendency, so that the mean and the standard deviation of the peak frequency for four subjects in respective atmosphere conditions were obtained. The peak frequency of thenar MV in some atmosphere conditions indicated no significant difference as compared with the control value in pre-compression by the paired t-test. The peak frequency of eyelid MV during 31ATA gave wide frequency range and the value during decompression increased by 18% in mean value, but those value also showed no significant difference with the control value by the paired t-test. The change of pressure till 31ATA did not necessarily influence MV frequency.

The amplitude of thenar MV and the change relative to the value at pre-compression increased after the pressure holding of 31ATA as shown in Fig. 3. The tendency was emphasized for eyelid MV; Especially, the amplitude at post-compression showed remarkable augmentation. The relative amplitude for thenar MV at post-compression and that for eyelid MV at decompression and post-compression were larger significantly by ten percent than the value at pre-compression by the paired

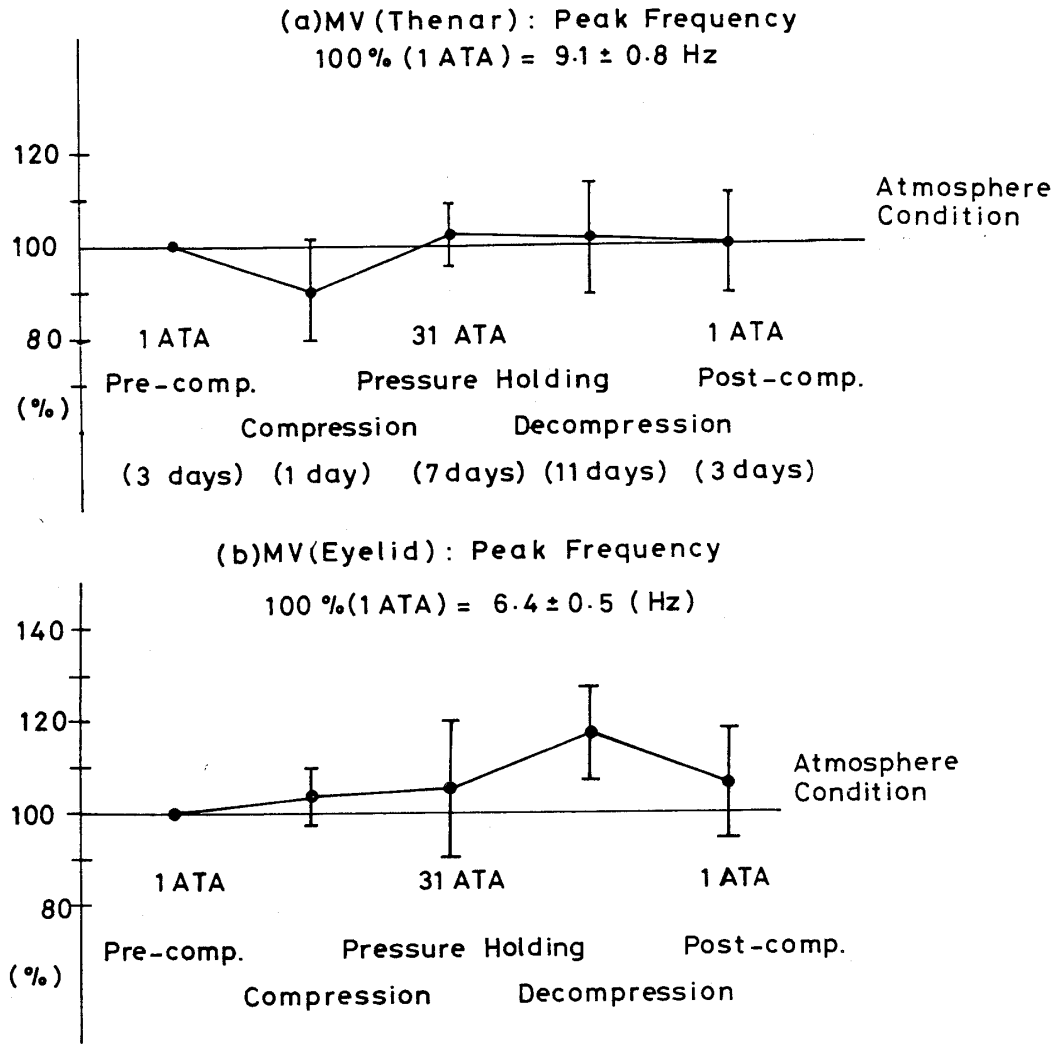


Fig. 2. Hyperbaric effect on MV peak frequency.
Conditions: Supine position, eye close, four subjects. (a) Thenar MV(right), (b) Eyelid MV(right).

t-test. Namely, the influence of hyperbaric environment on the amplitude of MV was recognized after the pressure holding. Such phenomenon was not found in physiological tremor(Fructus et al., 1969): The amplitude increased during pressure holding(e. g., Bachrach and Bennett, 1973a ; Seki et al., 1984) and it decreased during decompression below about 25ATA. The difference of modification of MV and physiological tremor by the atmosphere condition taken caused to the mechanism of generation(Usui et al., 1984b).

Various theories for the mechanism of MV have been proposed. Rohracher (1955), discoverer of MV, indicated the autonomic nervous system as the origin due to the existence of MV in only warm-blooded animal, and estimated the necessity of MV for thermo-regulation of body(Ohno et al., 1976). Sugano(1957) and Sugano and Inanaga(1958) asserted γ—motor system because of the disappearance of MV by the section of spinal cord (ventral root) in cat. Ozaki et al.(1962) emphasized ballistocardiogram origin because of the close relation between dominant MV amplitude and the waves R and T of ECG by the physiological experiment without surgical operation. The contribution of central nervous system to MV was recognized by photostimulation(Itoh, 1967), by the experiment of suggestion (Sugano and Inanaga, 1960), and by the close

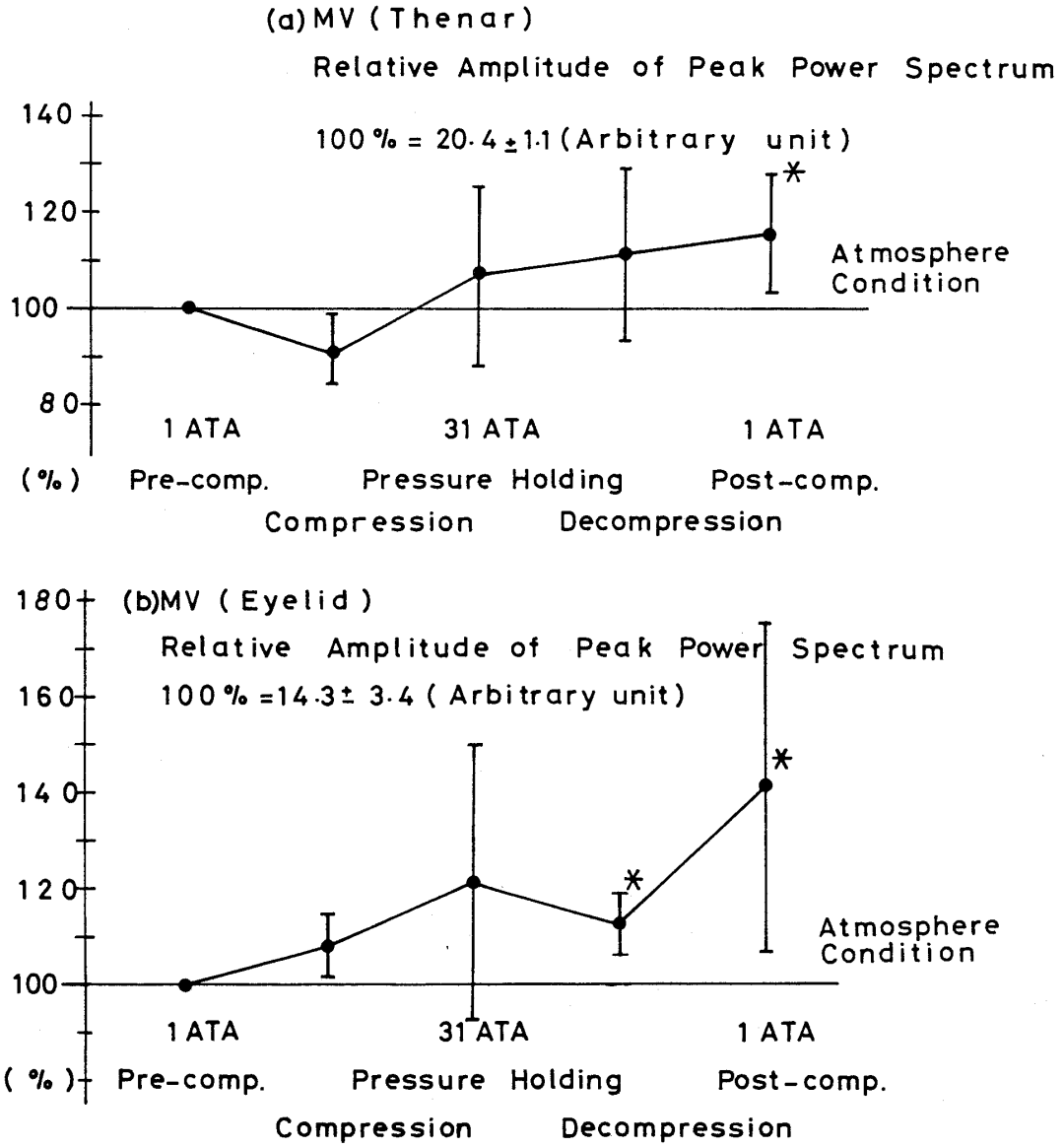


Fig. 3. Hyperbaric effect on MV relative amplitude of power spectrum at peak frequency.
See Fig. 2 for conditions.
(a) Thenar MV(right), (b) Eyelid MV(right)
The mark* means the significant level of ten percents as compared with the value at pre-compression by one-sided test of t distribution.

relation between MV and EEG in sleep(Usui et al., 1984a). MV in fatigue state of man showed the decrease of α band(8-13Hz) and the increase of θ band(4-8Hz) (Inoue, 1960). Although an established theory for the mechanism of MV is not yet obtained, the investigation of a great many papers published suggests that MV is generated not by one factor but by many factors, i.e., ballistocardiogram's component, γ—motor nervous loop, and central nervous system and so on (Usui et al., 1984b). Furthermore, it is considered that the functional alteration of nervous system like autonomic nervous system and γ—motor one contributes chiefly the change of MV frequency and that the functional alteration of cardiac output(i.e., component of ballistocardiogram) or the influence of skeletal muscle itself contributes the change of MV amplitude. The 31ATA experiment did not present the change of MV frequency statistically, so that the influence of hyperbaric environment and higher ambient tem-

perature(i.e., 31.5° C; see Fig. 1) on the nervous systems concerning spinal cord was slight. On the other hand, MV amplitude was affected not only by the pressure holding but also by decompression and post-compression. The phenomenon shows that any influence of high pressure on skeletal muscle(i.e., not motor nervous system but skeletal muscle itself) is considered and the influence contributes the change of ballistocardiogram component of MV, because the amplitude of eyelid whose muscle (i.e., m. orbicularis oculi) composes of the greater part of fast twitch fatigable fiber increased still more in the condition of post-compression. The interpretation is also considered to be reasonable from the results in other studies: That is, Mastuda et al. (1978) showed that in 11ATA heliox environment the value of heart rate(HR) decreased significantly by five percents significant level as compared with the value in pre-compression(1ATA), but the cardiac outputs which were origin of ballistocardiogram component denoted to be no significant; Seki and Nakayama (1979) presented no significant difference between HR's in 1ATA and 21ATA. From a few results for the circulation function, the effect of hyperbaric environment on the cardiac output was slight. Therefore, any change of skeletal muscle by high pressure is considered mostly to bring the change of the ballistocardiogram component of MV. However, the influence of pressure on physiological tremor is found mainly during both compression and pressure holding(Seki, 1979), because the contribution of motor nervous system including Renshaw cell was considered to play the dominant role of the generation(Hugon et al., 1983). Four subjects did not state any symptoms of HPNS during the experiment (especially, compression), so that the omen of HPNS was not detected by MV in 31ATA experiment. It is considered that the result was caused chiefly by the moderate compression rate of 25m/hr (cf. 180m/hr., Fructus et al., 1969; 720—1080m/hr., Rostain et al., 1980).

The results of peak frequency in EEG power spectrum for four subjects are shown in Fig. 4. The mean peak frequency at awake state with eye closed in pre-compression ranged from 8.8Hz to 10.2Hz. In compression, the peak frequency had a

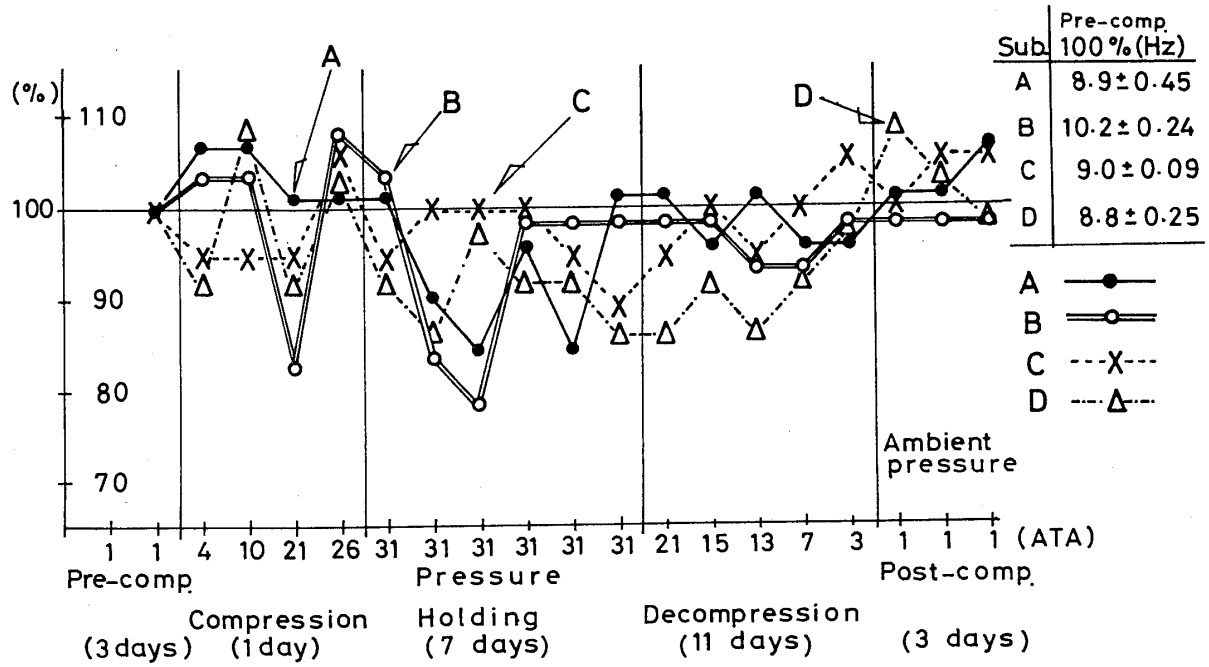


Fig. 4. Hyperbaric effect on EEG peak frequency.
Conditions: Supine position, eye close, T_4-O_2.
Subjects: A&B are scientists and C&D are professional divers.

tendency to lower, and in the pressure holding the inclination of lowering was emphasized. The peak frequency in the decompression was still lower than the control value in pre-compression, and the value in post-compression recovered again to the control value. These lowerings described above were recognized significantly by five percents significant level with the use of the paired t-test. The change of the peak frequency did not show individual difference between professional diver and scientist one. The experiment with high compression rate showed the increase of θ band(Fructus et al., 1969). Bennett and Towse(1971), Corroiol et al.(1973), and Rostain and Charpy(1976) reported the augmentation of θ band at the compression more than 31ATA. Futhermore, Fructus et al.(1969) and Seki and Hugon(1976) denoted the lowering of attention and the fall of critical flicker fusion frequency (CFF) with increase of the depth of heliox dive, respectively. The change of EEG, attention, and CFF meant that the level of consciousness dropped by the increase of compression. As compared with the compression of mixed gas of He and O_2, the application of compressed trimix gas He-N_2-O_2 more suppressed the appearance of HPNS and it made higher compression rate be possible, but a paroxysmal EEG wave manifested(Bennett et al., 1974). The modification of EEG depends on not only the compression rate but also the magnitude of pressure and the composition of environmental gas. The present experiment with moderate compression and with the most suitable environmental gas for HPNS also brought about the lowering of the level of consciousness because of the drop of EEG peak frequency.

Although the pressure environment of 13ATA did not influence the intentional tremor and the performance like ball bearing and peg board (Bachrach and Bennett. 1973b), Taya and Kuwabara(1982) showed the lowering of performance of tapping and peg board for the compression periods of 21ATA and 31ATA. The result was in good agreement with ours from the viewpoint of the lowering of level of consciousness.

The amplitude of power spectrum at peak frequency did not necessarily gave clear inclination by the change of atmosphere coditioins, so that the results were not shown here.

In conclusion, the influence of high pressure 31ATA on MV was made clear in the MV amplitude not in pressure holding but in post-compression. Therefore, the effect on body part remained after the compression, while the fluence on EEG was clarified in the frequency of EEG during compression, pressure holding, and decompression, that is, the effect on central nervous system was recognized. Those change of MV and EEG by the pressure 31ATA did nto mean the important functional disorder. The possibility of working in the heliox environment till 62ATA has been established(Seki, 1979), but the lowering of EEG frequency meant to call one's attention to some operation in the bottom of actual sea.

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BIBLIOGRAPHY

Bachrach, A.J. and P.B. Bennett, 1973a : Tremor in diving. Aerospace Medicine, 44 : 613-623.

Bachrach, A.J. and P.B. Bennett, 1973b : The high pressure nervous syndrome during human deep saturation and excursion diving. Försvarsmedicin, 9 : 490-495.

Bennett, P.B. and E.J. Towse, 1971 : The high pressure nervous syndrome during a simulated oxygen-helium dive to 1500 ft. Electroenceph. clin. Neurophysiol., 31 : 383-393.

Bennett, P.B., G.D. Blenkarn, J. Roby, and D. Youngblood, 1974 : Suppression of high pressure nevous syndrome in human deep dives by He-N_2-O_2. Undersea Biomedical Research, 1 : 221-237.

Brauer, R.W., S. Dimov, X. Fructus, P. Fructus, A. Gosset, and R. Naquet, 1969: Syndrome neurologique et électrographique des hautes pressions. Rev. Neurol., 121: 264-265.

Corroiol, J., J. Chouteau, and J. Catier, 1973: Human simulated diving experiments at saturation under oxygen-helium exposures up to 500 meters: Electroencephalographics data. Aerospace Medicine 44: 1270-1276.

Fructus, X., R. Naquet, A. Gosset, P. Fructus, and R. W. Brauer, 1969: Le syndrome nerveux des hautes pressions. Marseille Médical, 6: 509-512.

Hugon, M., L. Fagni, and K. Seki, 1983: Deep sea diving: Human performance and motor control under hyperbaric conditions with inert gas. Motor Control Mechanisms in Health and Disease, edited by J.E. Desmedt, Raven Press, New York, 39: 829-849.

Inoue, S., 1960: Sjudies on minor tremor. Fukuoka Acta Med., 51: 1240-1250 (in Japanese with English abstract).

Itoh, H., 1967: Photically evoked lid MV response from wakefulness to sleep in man. Jap. J. Physiol., 29:628-640 (in Japanese with English abstract).

Matsuda, M., H. Nakayama, H. Arita, J.F. Morlock, J. Claybaugh, R.M. Smith, and S.K. Hong, 1978: Physiological responses to head-out immersion in water at 11ATA. Undersea Biomedical Journal, 5: 37-52.

Ohno, Y., T. Takeya, K. Kuroki, and H. Sugano, 1976: Microvibration and autonomic functions. J. Psychosomatic Research, 20: 555-565.

Ozaki, T., K. Sato, T. Awazu, K. Mimura, N. Honda, S. Teramoto, and K. Kitajima, 1962: Some observations on minor tremors related to heart beat. Jap. J. Physiol., 12: 484-493.

Rohracher, H., 1955: Wärmehaushalt und Mikrovibration. Acta Neuroverg, 11: 187-200.

Rostain, J.C. and J.P. Charpy, 1976: Effects upon the EEG of psychometric performance during deep dives in helium-oxygen atmosphere. Electroenceph. clin. Neurophysiol., 40: 571-584.

Rostain, J.C., M.C. Gardette-Chauffour, and R. Naquet, 1980: HPNS during rapid compressions of men breathing He-O_2 and He-N_2-O_2 at 300m and 180m. Undersea Biomedical Research, 7:77-94.

Rostain, J.C., C. Lemaire, M.C. Gardette-Chauffour, J.Doucet, and R. Naquet, 1983: Estimation of human susceptibility to the high-pressure nervous syndrome. J. Appl. Physiol., Respirant. Environ. Exercise Physiol., 54: 1063-1070.

Seki, K. and M. Hugon, 1976: Critical flicker frequency(CFF) and subjective fatigue during an oxyhelium saturation dive at 62ATA. Undersea Biomedical Research. 13: 235-247.

Seki, K., 1979: HPNS: High pressure nervous syndrome. Respiration and Circulation, 27: 839-844(in Japanese).

Seki, K. and H. Nakayama- 1979: Sleep cycles in 21ATA He-O_2 environment for men. JAMSTECTR (JAMSTEC Technical Reports), 3: 160-168 (in Japanese with English abstract).

Seki, K., M. Iwasaki, N. Kuwabara, T. Nariai, Y. Taya, and H. Nakayama, 1984: Modification of postural tremors under a hyperbaric heliox environment at 31ATA in four divers. JAMSTECTR, 13: 121-131 (in Japanese with English abstract).

Spencer, J., A. Findling, A.J. Bachrach, R. Gelfand, C.J. Lambertsen, and G. Karreman, 1979: Tremor and somatosensory studies during chamber He-O_2 compressions to 13.1, 25.2, 37.3 and 49.4ATA. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., 47: 804-812.

Sugano, H., 1957: Studies on the microvibration. Kurume Med. J., 4: 97-113.

Sugano, H. and K. Inanaga, 1958: On the mechanism of minor tremor. Brain and Nerve, 10: 769-780(in Japanese).

Sugano, H. and K. Inanaga, 1960: Studies on minor tremor. Jap. J. Physiol., 10: 246-257.

Taya, Y. and N. Kuwabara, 1982: The influence of hyperbaric environment on fatigue in human deep

dive. The 8th Congress of the International Ergonomics Association, 298-299.

Usui, T., K. Sakamoto, and K. Seki, 1984a: Correlation between eyelid microvibration and electroencephalogram at various sleep stages in man. Annals Physiol. Anthropology, 3: 75-77.

Usui, T., K. Sakamoto, and H. Okuno, 1984b: Mechanism of mechanical vibrations in living body and its application to various fields. Annals Physiol. Anthropology, 3: 177-193.

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