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Critical flicker frequency (CFF) and subjective fatigue during an oxyhelium saturation dive at 62 ATA

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Seki, K., and M. Hugon. 1976. Critical flicker frequency (CFF) and subjective fatigue during an oxyhelium saturation dive at 62 ATA. Undersea Biomed. Res. 3(3):235–247.—Two divers spent over 50 hours at 610 msw in a helium–oxygen mixture (P_{O_2}: 0.38–0.52 ATA). The dive duration was 27 days, including predive stages of confinement, compression, time at maximum pressure, and decompression. The divers were asked to answer 30 questions on their feelings of mental and physical fatigue and to indicate on a nine-point scale their estimation of a general feeling of fatigue. Subjective feelings of fatigue reported in this dive suggested that the divers were in good condition. Hyperbaric arthralgia and physical complaints were reported, especially during decompression, with some postdive persistence, but they should be considered as distinct signs of feelings of fatigue. The critical flicker frequency (CFF), measured throughout the dive for the two divers, showed systematic variations and a relationship between compression and pressure. These variations were grossly parallel to EEG modifications reported in other studies and probably reveal neurophysiological troubles that were not apparent from subjective reports.

fatigue
critical flicker frequency (CFF)
divers
helium–oxygen

Fatigue is defined as a subjective feeling of tiredness. McNelley (1966) has described a nine-point scale of estimation for subjective fatigue, ranging from (1) "terrific" to (9) "about to fall over." Other writers have worked out synthetic evaluations of subjective fatigue from standard questions related to familiar aspects of fatigue: Japanese (Kirihara 1949; Yoshitake 1970; Kogi, Saito, and Mitsuhashi 1970), American (Wolf 1967; Kinsman, Weiser, and Stamper 1973), and French (Bugard 1960, 1974; Desoille, Scherrer, and Truhaut 1975).

There is usually a good congruency between synthetic evaluation of the fatigue feeling and the global subjective estimation through the McNelley procedure. After considering these methods and their results, we believed it would be possible to investigate fatigue in hyperbaric conditions using subjective questionnaires instead of objective testing, which involves a time-consuming and complex apparatus and unrealistic conditions.

Such an inquiry, however, is subject to several influences, such as suggestion, repetition, and personal considerations of the divers. To test the objectivity of the fatigue reports, we asked each diver to stop a flashing apparatus on the specific frequency that evoked a sensation of flickering known as critical flicker frequency (CFF).

CFF performance is considered an individual capability, which decreases as a function of fatigue of the central nervous system (Simonson and Enzer 1941; Simonson 1959, 1971; Oshima, Kuroe, Hase, Yamanaka, and Endo 1952; Grandjean and Perret 1961; Grandjean 1968; Hashimoto 1961; and Weber, Jermini, and Grandjean 1975). The CFF decreases under specific factors, such as low vigilance or drugs (Bartley 1936; Walker, Woolf, Halstead, and Case 1943; Fuster 1957; Linsley 1957; Kogi 1961; Pieron 1965; Sturr and Shansky 1971; and Van de Grind, Grusser, and Lunkenheimer 1973). Testing has some degree of objectivity when the subject is kept away from any information about his or her own performance. Finally, CFF testing is easy to manage at depth, requires only a small apparatus, and is not time-consuming.

METHODS

Description of the Dive

The chamber complex used was the new CNEXO/COMEX *EMS 600* modular system at the Centre Experimental Hyperbare de la COMEX, Marseille.

Two professional divers, 27 and 28 years old were the subjects in the SAGITTAIRE-IV dive to 610 msw. After the operation was started with a 4-day confinement, the pressure was increased by stages from 1.8 to 62 ATA over 11 days. The divers stayed at 62 ATA for 50 hours, then were decompressed to the surface in 10 days. The partial pressure of oxygen in the helium–oxygen mixture was kept between 0.38 and 0.42 ATA during compression and saturation, and between 0.49 and 0.52 ATA during decompression.

Relative humidity and ambient temperature were adjusted for comfort to range from 45 to 60% and 26 to 33.8°C, respectively.

Subjective Evaluation of Fatigue

Three tests were used to determine divers' subjective evaluation of fatigue. These tests, described below, were administered once every morning and again each evening. No precautions were taken to avoid learning or repetitive effects. The answers of the divers were made independently and answer sheets were collected after each session to avoid mutual influence.

Subjective symptoms of fatigue (SSF) The well-known questionnaire from the Industrial Fatigue Research Committee of the Japanese Association of Industrial Health (Kogi et al. 1970; Yoskitake 1971) was selected. The questionnaire asks a subject 3 series of 10 yes-or-no questions about his feelings of subjective symptoms of fatigue (Fig. 1). The index for this test was the total number of "yes" responses.

Analysis of bodily subjective fatigue (ABSF) Because we were aware that hyperbaric arthralgia (Hamilton, MacInnis, Noble, and Schreiner 1966) as well as other problems might occur, we used a drawing of the human body with 50 specific areas numbered (Fig. 2). Subjects were asked to point out on this drawing exactly where they felt pain or discomfort.. The index for this test was the total number of uncomfortable areas.

Rating of feeling of fatigue (RFF) For an estimation of tiredness the subjects were asked to describe their general feelings of fatigue on a subjective scale (McNelley 1966). We asked divers to rate fatigue by marking an appropriate number on the following scale: (1) terrific; (2)

Questionnaire: Subjective Symptoms of Fatigue (SSF)

N°
Name______ Date____/197___ Hour______
Depth______ P_{O_2}______ mb H_2O______
Temp.____°C____

These questions ask about your state of body. Answer all the following questions with *yes* or *no*.

A. *YES* *NO*

1. Head feels heavy ______
2. Whole body feels tired ______
3. Legs feel tired ______
4. Want to yawn ______
5. Brain feels hot or muddled ______
6. Become drowsy ______
7. Eyes feel strained ______
8. Become rigid or clumsy in motion ______
9. Feel unsteady in standing ______
10. Want to lie down ______

B.

11. Thinking is difficult ______
12. Become wary of talking ______
13. Become nervous ______
14. Unable to concentrate attention ______
15. Unable to have interest in things ______
16. Apt to forget things ______
17. Lack of self-confidence ______
18. Anxious about things ______
19. Unable to straighten up in a posture ______
20. Lack patience ______

C.

21. Have a headache ______
22. Feel stiff in the shoulders ______
23. Feel a pain in the back ______
24. Breathing feels oppressed ______
25. Feel thirsty ______
26. Have a husky voice ______
27. Feel dizzy ______
28. Have a spasm on the eyelids ______
29. Have a tremor in the limbs ______
30. Feel ill ______

Fig. 1. Checklist of the subjective symptoms of fatigue.

very good; (3) in gear; (4) fairly well; (5) average; (6) a little tired; (7) let down; (8) fagged; and (9) about to fall over.

CFF Evaluation

A binocular foveal flickering target was presented to the subject through a SHIBATA–FL–AO apparatus (Fig. 3). The flicker stimulus delivered frequencies from 60 to 10 Hz and maintained a light-dark ratio of one. The flickering target had a diameter of 0.5°, a 500-lx

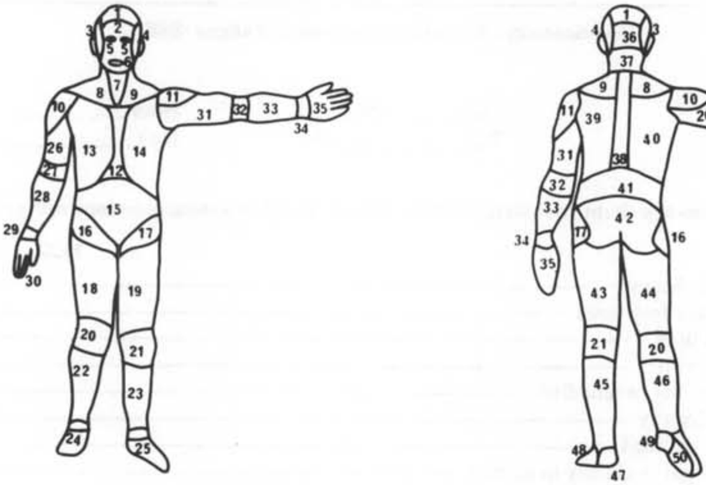

Fig. 2 Check scheme of the analysis of bodily subjective fatigue (ABSF). (Drawing from Seki 1972)

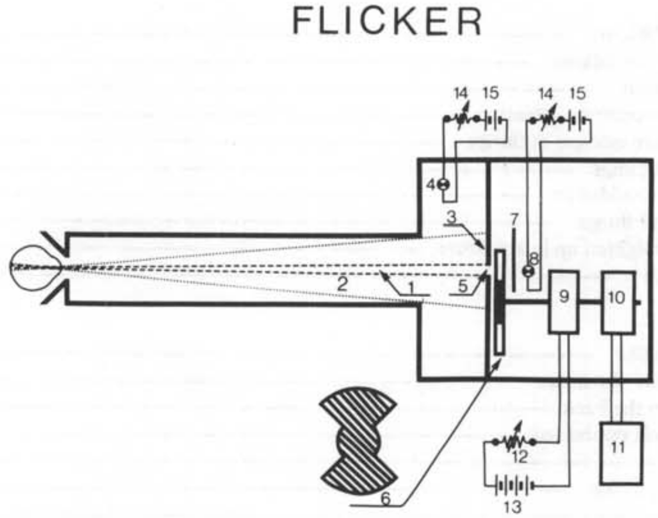

Fig. 3. Schematic diagram of speed control and optical system. Some apparatus parts, 1–10, are situated in the hyperbaric chamber. The other parts, 11–15, are external, maintained in normal atmospheric conditions.

illumination, and a 5°, 100-lx surrounding. Adaptation of the subjects was fast because experiments were performed in a room at ordinary illumination, not very different from the target background.

The flickering apparatus started at 60 Hz. Frequency was then decreased linearly by 2 Hz. The subject was required to stop the decrease by pressing a button as soon as flicker was noticed; the corresponding frequency was then read on the frequency meter. This apparatus could perform only the decreasing method of limits.

Five consecutive measures were taken; the arithmetic mean gave the central tendency of the performance. After some training sessions under these conditions, the subjects' performances were stable with a standard deviation of approximately 0.25 of the mean value. Subjects were not told the results. Two daily sessions were performed, one in the morning (0800 h) and the other in the evening (1800 h).

RESULTS

Table 1 gives the data from the two subjects for SSF, ABSF, RFF, and the CFF.

TABLE 1
General results

SAGITTAIRE IV
62 ATA: 2 days
June 1974

		Subject *a*				Subject *b*			
		CFF	SSF	ABSF	RFF	CFF	SSF	ABSF	RFF
Surface–12 days *N*=24	$\bar{x}$	42.5	0.2	0.3	2.7	44.9	0.1	0.5	2.7
Confinement–4 days *N*=8	$\bar{x}$	39.3	0.1	0.1	2.2	42.3	0.5	0.6	2.1
Compression–11 days N=22	$\bar{x}$	35.0	0.3	1.5	2.6	38.5	0.3	2.0	2.0
Saturation 62 ATA–2 days *N*=4	$\bar{x}$	32.8	0	1.0	3.0	37.7	0.7	3.5	2.0
Decompression–10 days *N*=20	$\bar{x}$	36.4	0.3	5.0	2.6	40.4	0.9	5.4	2.2
Return to surface–2 days *N*=4	$\bar{x}$	42.5	6.5	7.0	6.0	43.3	2.5	6.5	3.0

CFF = critical flicker frequency.
SSF = subjective symptoms of fatigue.
ABSF = analysis of bodily subjective fatigue.
RFF = rating of feeling of fatigue.
$\bar{x}$ = arithmetic mean.
N = number of tests

Subjective Fatigue Data

Subjective symptoms of fatigue (SSF) Figure 4 shows the results from the evaluation. Since there was a very low level of fatigue throughout the dive, including the decompression phase, the distribution of subjective symptoms is not Gaussian and the use of a standard deviation makes no sense. Symptoms of fatigue increased during decompression, however, and after the return to normal atmospheric conditions. The behavior of the two divers was similar in this respect.

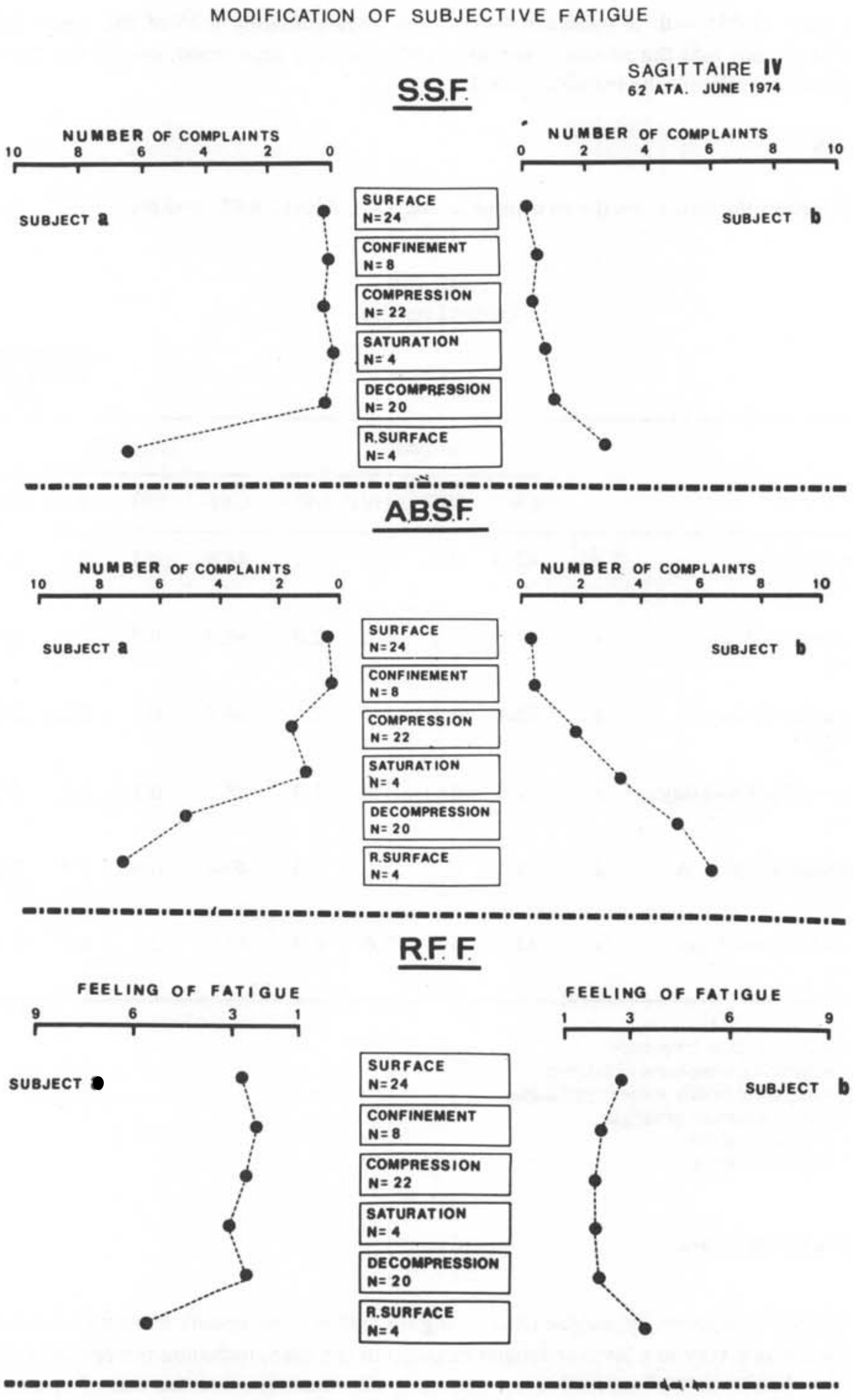

Fig. 4. Average number of complaints for SSF, ABSF, and RFF during specific dive phases. *N* represents the number of tests conducted during each phase of the dive.

Analysis of bodily subjective fatigue (ABSF) ABSF scores reflect the muscular and joint discomforts, including over-fatigue, hyperbaric arthralgia, and any physical troubles. As shown in Fig. 4, physical complaints increased during decompression. Complaints did not increase as much during the saturation stages at depth. Some postdive effects were also mentioned. The usual areas of complaint were the wrists, shoulders, hips, and knees.

Ratings of feeling of fatigue (RFF) The general feeling of fatigue was very low throughout the dive, as shown by Fig. 4. After the return to normal atmospheric conditions, RFF increased for the two divers. Results are roughly similar to the SSF evaluation, but are different from ABSF (specifically for the saturation and decompression stages).

Critical Flicker Frequency Data

Figure 5 shows the CFF variations of Subjects *a* and *b* at depth. Each point represents five measures from the series taken in the morning (0800 h) and in the evening (1800 h). The following points can be observed:

1. In a normal situation at the surface (air: 1 ATA), the CFF values for the subjects were:

Subject a	42.9 Hz: SD = 0.69 in the morning
	42.9 Hz: SD = 0.16 in the evening
Subject b	44.9 Hz: SD = 0.18 in the morning
	44.0 Hz: SD= 0.27 in the evening

The CFF value of Subject *b* was significantly lower in the evening than in the morning ($P<.01$).

2. The heliox confinement (1.8 ATA) gave significant decrease of the CFF ($P<.01$).

3. Compression, considered in its totality, provoked a decrease in the CFF for the two divers.

4. During any stage (41, 56, and 62 ATA), there was a slight recovery of the CFF for the two subjects; however, the recovery is not as important as the general modification of the CFF at the corresponding pressure.

5. During decompression, there was a quick but partial recovery of the CFF.

Correlation of Results

Correlations of data on SSF, ABSF, RFF, and CFF threshold for the two subjects and on depth, humidity, partial pressure of oxygen, and ambient temperature are presented in Table 2. The strongest correlations are between the CFF and the depth ($P<.01$) and the CFF and ambient temperature ($P<.01$). The CFF decreases with depth and the ambient temperature increases with depth.

The CFF for Subjects *a* and *b* are strongly correlated ($P<.01$), as well as for the ABSF ($P<.01$). The general feeling of fatigue (RFF) and the CFF are correlated in Subject *a* only.

DISCUSSION

Validity of the Data

Quantification of the responses in subjective ratings is a disputable method, and only comparative results make some sense (for specific discussion, *see* Seki 1972). Possibilities of bias

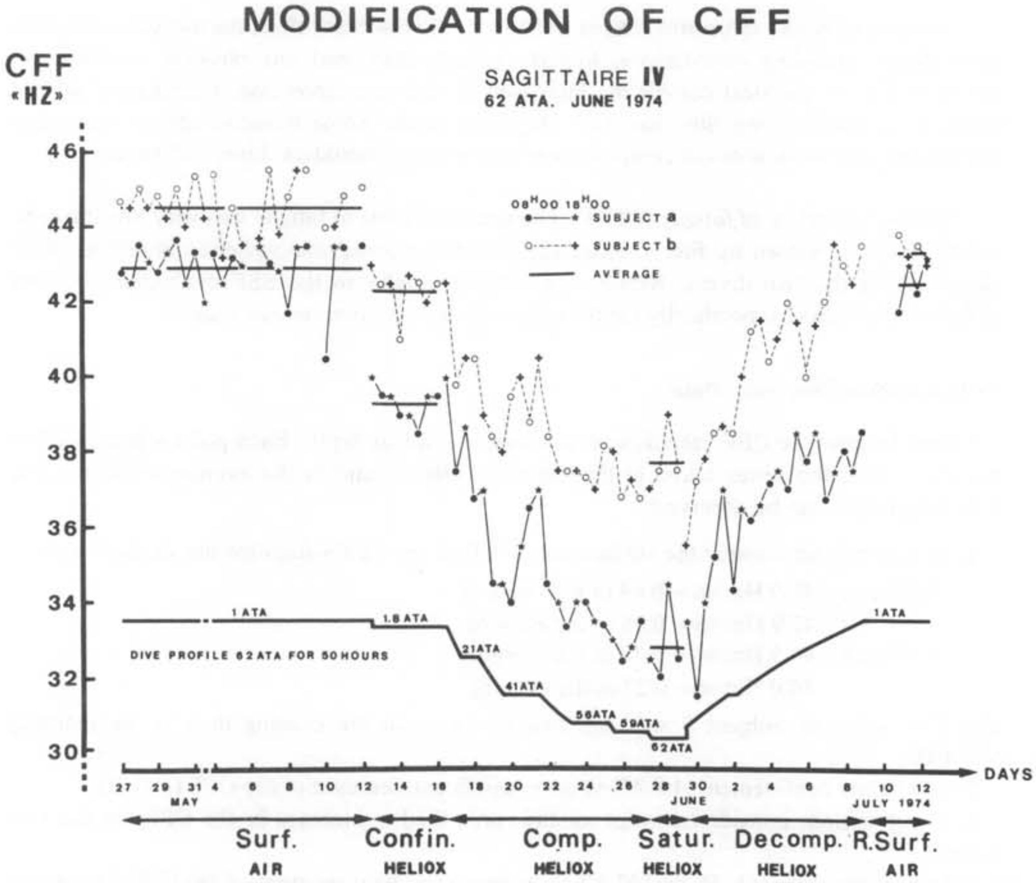

Fig. 5. Individual variation of CFF during experiment shift and the dive-profile of an oxygen–helium experiment in man (Hugon 1975).

are of great concern in the subjective evaluation of fatigue. Divers do know their own responses, yet there is a possibility of one influencing the other. Divers also know the depth and its usual consequences. For social reasons the divers might be over-motivated and their evaluations modified. In this study the daily lives of the divers were not controlled after the return to normal air, and the possibility of extraneous factors of fatigue cannot be ruled out. Reports from friends and relatives, however, do confirm the very low level of subjective fatigue during the diving and the existence of strong postdive effects.

Such reports should be compared with results from a study of reflexes (Roll, Lacour, Hugon, and Bonnet 1975) and ocular performance (Gauthier 1975), which persisted after the return to the surface (Hugon 1975). Finally, there is a coherence in results from 10 similar independent studies (Seki 1976), including the present one, which suggests a restricted influence from systematic biases. That increasing frequencies in normal air were not measured in the CFF studies is apparently not important. Evaluation of the CFF through the decreasing-frequency method of limits gives the same values as those obtained through the increasing procedure, with a systematic deviation of 0.5 Hz (Hashimoto 1961). Therefore, even though variations rather than absolute values are reported, we may consider the present results as significant despite the simplified procedure used.

TABLE 2
Correlation matrices

SAGITTAIRE IV
June 1975

		Depth	Humidity	PO$_2$	Ambient Temperature	Subject *a*				Subject *b*			
						CFF	SSF	ABSF	RFF	CFF	SSF	ABSF	RFF
Depth		1.000	−0.308†	−0.095	0.739‡	−0.933‡	0.024	−0.032‡	0.639‡	−0.928‡	−0.025	0.135	−0.214
Humidity		−0.308†	1.000	−0.257	−0.355†	0.440‡	−0.026	−0.139	−0.284*	0.261	−0.279*	−0.153	0.089
PO$_2$		−0.095	−0.257	1.000	0.235	0.034	−0.081	0.236	−0.019	0.054	0.213	0.453‡	0.276*
Ambient Temperature		0.739‡	−0.355†	0.235	1.000	−0.706‡	0.039	0.066	0.452‡	−0.656‡	0.010	0.267	−0.011
Subject *a*	CFF	−0.933‡	0.440‡	0.034	−0.706‡	1.000	−0.091	−0.009	−0.629‡	0.880‡	−0.050	−0.160	0.204
	SSF	0.024	−0.026	−0.081	0.039	−0.091	1.000	0.231	0.095	−0.083	0.039	0.130	−0.028
	ABSF	−0.032	−0.139	0.236	0.066	−0.009	0.231	1.000	0.324*	−0.092	0.145	0.523‡	0.021
	RFF	0.639‡	−0.284*	−0.019	0.452‡	−0.629‡	0.095	0.324†	1.000	−0.555‡	0.176	0.301*	0.134
Subject *b*	CFF	−0.928‡	0.261	0.054	−0.656‡	0.880‡	−0.083	−0.092	−0.555	1.000	0.058	−0.055‡	0.227
	SSF	−0.025	−0.279*	0.213	0.010	−0.050	0.039	0.145	0.176	0.058	1.000	0.418‡	0.376‡
	ABSF	0.135	−0.153	0.453‡	0.267	−0.160	0.130	0.523‡	0.301*	−0.055	0.418‡	1.000	0.432‡
	RFF	−0.214	0.089	0.276*	−0.011	0.204	−0.028	0.021	0.134	0.227	0.376‡	0.432‡	1.000

Experiments during 27 days; number of tests = 54. * $P < 0.05$, † $P < 0.02$, ‡ $P < 0.01$.

Hamilton, Schmidt, Kenyon, Freitag, and Powell (1974), during short saturation stages to 31 ATA, report "uniformly unremarkable results." This marked discrepancy may be due to differences in apparatus or procedure. Apparently Hamilton et al. used monocular testing and gave the subjects an opportunity to adjust their decisions by successive trials, using increasing and decreasing frequencies of illumination.

The authors believe that the CFF correlation with the deep diving in this study did not result from technical impairment of the apparatus because the stability of the apparatus had been checked at 101 ATA (heliox, from −5 to +40°C) in a separate dive (Seki and Hugon 1974; 1975a, b; *in press* a) and was found excellent.

Significance of the Results

Comments on CFF

1. Surface air results are classical in respect to absolute values and variability; such normality is an external validation of the procedure and gives a valuable reference for the dive data.
2. The parallel variations of the CFF for the two divers strongly suggest a biological defect related to the pressure. Grivel (1971) has shown positive correlation between external ambient temperature and the CFF ($P<.01$). A mean increase of 2 Hz is observed after 5 h at 32°C (from 25°C). If the same variation occurs in heliox at depth, an elevation of the CFF of about 2 Hz would be expected for an increase of +7.8°C. In other words, the CFF decrease due to pressure was probably underestimated by about 2 Hz, because of cumulative effects of pressure and temperature.
3. The correlation between pressure and CFF values at depth was calculated from the total pool of CFF values, including morning and evening scores (two subjects, $P<.01$). The hypothesis is that variations of the CFF are a Gaussian noise around a CFF mean value correlated with pressure.

Closer examination of the results suggests a better understanding of the actual situation. Stages at constant depth (21, 41, and 62 ATA, and possibly 56 ATA) produce a recovery of CFF in the two subjects that may be called *adaptation to pressure*, but it is only partial; it suggests that after an important stress caused by variation of pressure, there is residual stress from the pressure. We therefore consider the distinct effects of compression and pressure a confirmation of EEG conclusions (Hunter and Bennett 1974; Rostain and Naquet 1975). This is an objective argument for the introduction of stages in compression profiles (Fructus, Agarate, and Rostain 1973).

4. Recovery of the CFF comes during the 2 days of staging, a duration much longer than the theoretical time for the saturation of the *slower* tissues (6 h). This difference suggests that what we have called the adaptive increase of CFF depends not only on diffusion processes, but also on slower processes, possibly *structural*, which concern the membrane organization or related organs.
5. Rostain and Naquet (1975), describe EEG modifications (increase in slow rhythms and microsleep), which are signs of central neurophysiological disturbance as well as cortical or subcortical defects, due to compression (speed, absence or presence of stages, number and depth of stages) and pressure per se. Observations from Hugon and Lemaire (1975) and Hugon (1975) clearly confirm that properties of the peripheral neuron system (excitability, velocity in sensory or motor fibers) are not impaired at depth. Similarly, CFF variation at depth should be due to some defect in central structure (neuropile, synapses, glial or blood system).

Physiological writers on the CFF in animals (in air at 1 ATA) point out the role of reticular formation, occipital and frontal cortices, and rhinencephalic areas (Walker et al. 1943; Bartley 1959; Kogi 1961; Sturr and Shansky 1971; Van de Grind et al. 1973).

Confirmatory, comparable defects in somesthetic discriminations (in man at depth) suggest some nonspecific central trouble of processing (Seki and Hugon 1975a, *in press* a; Seki 1976). Our interpretation favors the central nervous defect hypothesis rather than sensory trouble.

Comments on subjective evaluation

1. The lack of consistent correlation between subjective evaluations seems to be due to the low level of fatigue feelings. A small variation in the wording of one question to another may appear large in regard to the mean value of the response. In other words, the questionnaire we used may have been suitable in studies where subjects were relatively tired but was a crude instrument considering the subtleness of the symptoms in this study.
2. Physical complaints through ABSF evaluation from Subjects *a* and *b* are strongly correlated. In such cases symptoms are unambiguous, and mention of their presence is of clearer evidence. Results are signs of similar organic problems in the two divers (hyperbaric arthralgia and decompression accidents) (Seki and Hugon 1973; Seki 1976; Bradley and Vorosmarti 1974).

There was no correlation in this experiment between CFF modification and subjective general evaluation of fatigue. So, the CFF does not appear as a symptom of fatigue in such a situation. Simonson, Kogi, and others concluded differently from studies in normal air. The question arises whether the CFF modification in high-pressure heliox has the same physiological meaning as it does in normal air, when caused by tiredness. CFF modification could be correlated with some specific aspect of the hyperbaric impairment.

On the other hand, CFF modifications indicate central nervous system problems comparable to EEG or reflex modifications. In this respect, CFF does appear an objective and useful indication of a psychophysiological impairment at depth.

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Seki, K., et M. Hugon. 1976. Fréquence critique de papillotement et fatigue subjective en plongée à saturation (oxygène–helium—62 ATA). Undersea Biomed. Res. 3(3):235–247.—Deux plongeurs ont séjourné 50 heures à une profondeur fictive de 610 mètres sous mélange d'Helium et d'oxygène légèrement hyperbare (0,38 - 0,52 ATA). La plongée a duré 27 jours (confinement, compression, séjour au fond, décompression). Les plongeurs devaient répondre à trente questions relatives à la fatigue perçue, physique ou mentale, et indiquer sur une échelle en neuf points l'appréciation globale de leur état de fatigue. Les resultats obtenus témoignent du bon état mental des plongeurs durant la plongée; des arthralgies hyperbares et des douleurs musculaires ont cependant été signalées, notamment durant la décompression. Certains troubles ont persisté après le retour en surface. Ces troubles physiques ne sont pas considérés comme homogènes à la sensation ordinaire de fatigue. La fréquence critique de papillotement (CFF - critical flicker frequency), mesurée chaque jour aux diverses périodes de la plongée a montré, pour les deux plongeurs des diminutions systématiques liées à la pression et à la vitesse de compression. Ces variations de CFF ont été comparées aux troubles eeg observés pendant la même plongée; on considère qu'elles révèlent des troubles neurophysiologiques que les rapports subjectifs ne détectent pas.

fatigue
fréquence de papillotement
plongeurs
helium–oxygène

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