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CAN THE CRITICAL FREQUENCY OF FUSION OF INTERRUPTED ELECTRICAL STIMULATION OF THE EYE SERVE AS A TEST OF FATIGUE

Differing from the test of the C. F. F. of interrupted stimuli of light, which some authors used to investigate fatigue, the authors attempted to use the C. F. F. of interrupted *electrical* stimulations of the eye as a test of fatigue. The results show, that the C. F. F. of interrupted electrical stimulations of the eye does not change in the state of fatigue. Therefore, that test can not serve as a test of fatigue.

INTRODUCTION

The investigation of various phenomena of fatigue is hampered considerably, because, as yet, we do not possess such a fatigue test, by which we could ascertain and measure fatigue. Almost all important physiological, biological and psychological tests have been tried out also in this field, but, among these, there is not one which would be a valid indicator of the degree in which the general working capacity of the organism is impaired. The chemical changes in the organism, the changes in the function of the various organs, and the changes in the nervous activity, which result from long or intensive work, are not always in correlation, and that is why one-sided testing of these changes has a relatively low diagnostic value.

Because the nervous system considerably participates in all professional work, the so-called psychological tests are of especial importance; by means of these tests an attempt is made to get a view into the functional condition of the highest nervous structures. Such tests have regularly a basic shortcoming, in so far as the results are much influenced by the motivation of the subject, because he may – since the testing is necessarily short – unintenionally not only mask, but also overcompensate the eventual changes in the C. N. S., due to fatigue. That is true for tests of mental capacities as well as for psychomotor tests. The psychological sensibility tests are somewhat more reliable, because, during the investigation of the different sensory functions, that subject is not, as a rule, in a position either to control or to influence significantly his results by his greater effort.

Among these sensory tests of »fatigue«, the C. F. F. of interrupted stimuli of light has been much studied recently.

As it is known, if interrupted stimuli of light, of relatively low rate, act upon the receptor of vision, the subject will have a discontinued visual sensation. When the frequency of the stimuli is increased, the subject will percept a flicker, and if the interruption becomes even faster, fusion will result, i. e. the visual sensation will be continued, though the objective stimulus is discontinued. The frequency of the stimuli, which is just large enough to provoke a continued visual sensation, is called the critical frequency of fusion (C. F. F.).

The C. F. F. test is used in ascertaining some functional characteristics of the visual receptor (apparent persistence of the visual sensation), and in the field of fatigue, it was first used by H. PIÉRON (1). This author found, that, after intensive effort on the dynamograph, there was a definite decrease in the C. F. F. which on the average was 5 per cent. Verification of how the C. F. F. is influenced by mental work, did not give clear results. PIÉRON holds, that the increase in the apparent persistence of the visual sensations in the fatigue phase, is possibly connected with the increase in the differential threshold brought about by the lowering of sensitivity.

Further investigations, which were carried out by this test, did not give uniform results.

Among the authors, who found statistically significant decreases in the C. F. F. in the fatigued state, prominent are E. SIMONSON and N. ENZER (2), and H. SCHMIDTKE (3).

SIMONSON and ENZER measured the C. F. F. at the beginning and at the end of a working day, on a large number of office, laboratory and professional workers. In all their subjects, the C. F. F. was 3–7 cycles per sec. lower at the end of the working day than in the morning. The authors think that, as a test, the C. F. F. is a good indicator for general fatigue of the C. N. S., because the C. F. F. is closely related to the time characteristics of the excitability of the nervous and receptor tissues (chronaxia, latent period, and the refractory phase). The more a neural system can follow a larger number of objectively interrupted stimuli, its functional state is better.

H. SCHMIDTKE especially studied the influence of prolonged mental work (addition through 3 hours) on the C. F. F., and found that it decreased, on the average, by approximately 11 per cent. Fatigue, provoked by loss of sleep, acts similarly.

The authors mentioned, and others (4), (5), (6), (7), (8), (9), attempted to evaluate the effect of different factors on the C. F. F., and, in most cases, found that the various excitant substances (caffeine, methyltesterone, benzedrine) increase that frequency, while depressant substances or states decrease it (old age, anoxia, hypothyroidism, evipan).

The results of R. H. LEE (10), R. A. MCFARLAND, A. H. HOLWAY and L. M. HURVICH (11), J. BROŽEK and A. KEYS (12), are somewhat different.

LEE measured the funsion frequencies on drivers, after they had driven an uneven number of hours, and found that the C. F. F. is somewhat decreased, on the average, with the number of hours driven, but that that fall was not statistically significant.

MCFARLAND and his co-workers measured the intensities of light, which were just large enough to result in a fusion of stimuli of constant frequency. He carried out these measurements on subjects who worked mentally throughout the whole day, and he did not find any significant difference between the critical intensities in the morning and in the afternoon. The apparent persistence of visual sensations was somewhat increased only after longer sleeplessness, i. e. in these situations the critical intensities of the stimuli for constant frequency was somewhat augmented.

Finally, systematic research by BROŽEK and KEYS showed that the C. F. F. decreases only when the organism does hard work under unfavorable internal and external conditions, and that even then, the differences are often statistically insignificant. On the bases of their results, the authors conclude that the flicker fusion test cannot be held as a sensitive indicator for general fatigue.

The different results, to which the above-mentioned authors came, can be partially explained by the fact that the C. F. F. is influenced by a large number of factors, which are not easily held constant, and because, fatigue, at least theoretically, can unevenly influence the various factors upon which fusion depends.

As it is well known, the C. F. F. depends on the duration of the persistence of the visual sensation within the limits of the differential threshold. Thus the variations in the value of the critical interval, which just evokes a fusion, can be influenced by the changes in the real persistence, by the changes in the differential sensitivity, or by the variations of the one and the other factor (13).

The real persistence of the visual sensation, and the differential sensitivity depend on a great many other factors, such as: the adaptation states of the eye, the intensity and the duration of the stimulus, the relation between the duration phase of the stimulus and the phase of interruption, the size of surface excited, the stimulated area of the retina, the diameter of the pupil, etc. Some of these factors are closely correlated, while others are again varying independently.

Besides that, the mechanism of fusion and the sensitive structure responsible for the impression of continuity of the objectively interrupted stimuli are, as yet, not known. On the basis of the photochemical theories of vision, fusion results, when there is an equilibrium between the decomposition of photosensitive materials and its spontaneous regeneration in the phase of interruption. By this conception, the photochemical processes of the retina would be at the root of fusion. However, there are a large number of indications, which point out, that the process of fusion can also depend on the relatively slow changes in the potential

of the ganglial cells of the retina. When stimuli follow each other in relatively quick succession, the positive deflection of the electroretinogram is uninterrupted, and at the same time, the fluctuation ceases in the intervals between the successive nervous impulses, which are carried to the centers (14). Lastly, on the bases of his experiments with interrupted light stimuli, J. SEGAL (15) holds, that the fusion is of a central origin, i. e. that it is based on processes, evolving in the cortex of the brain.

The C. F. F. research is either carried out with a rotating disk with black and white sectors, or with interrupted stimuli of light. But, a visual sensation can be produced also by electric stimulation of the eye. If we apply interrupted electric stimuli of a large enough intensity, and at low frequencies, the subject will have intermittent visual sensation. When the rhythm of the electric stimuli is increased, the sensations of light will change at first into flicker, then with a still higher increase of frequency, there will only be a short flash, when the electric circuit is just closed.

This method of provoking a visual sensation has that advantage, in comparison with the adequate stimulation of the eye, that the electric current acts direct upon the afferent fibers of the optic nerve. Thus almost all changes, which can result in the function of the visual apparatus caused by peripheral processes of the retina, cannot influence the results.

Because electrical phosphenes are influenced by a smaller number of factors than the normally provoked visual sensations, we thought it interesting to investigate, *whether fatigue, which is the effect of physical or mental work, influences the C. F. F. of interrupted electrical stimulation of the eye.*

METHOD

We provoked electric phosphenes with rectangular electric pulses, one following the other. The action phase of every current pulse lasted as long as the phase of interruption.

The arrangement consisted of a constant current source, a potential divider, and a mechanical rotating interrupter in connection with a motor and a speed variator *(fig. 1)*. In order to diminish the influence of the variability in the resistance of the subject's body, a resistance of 20,000 Ω was inserted in the series with the subject. The nonpolarisable electrodes were of zinc and zinc sulphate. During the experiment, the subject held the active electrode on his right temple, while the palm of his left hand rested upon the indifferent electrode. The active electrode (cathode) had a tampon of agar-agar jelly, made with zinc sulphate. That part of the electrode, which was in contact with the subject's skin had a diameter

of 1.0 cm. The indifferent electrode (anode) consisted of a zinc plate 10 cm. in diameter, and was wound in cotton, which was imbibed with 5 per cent of zinc sulphate. Before each experiment, the parts of the skin, on which the electrodes were placed, were cleaned by scraping and with alcohol. The subjects were adapted to a luminance of around 1 apostilbe, and during the experiment, they fixed their eyes upon a white spot on a dark grey curtain.

The experiment began with a measurement of the threshold for continued stimulus by the method of constant stimuli. After the threshold was found, we took a stimulus three times larger than the threshold intensity. For this intensity we measured the C. F. F. We worked on the thrice threshold intensity level, because that intensity does not yet produce sensations of touch and pain, and phosphenes are clear enough

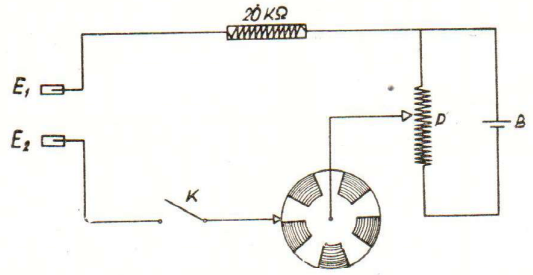

Fig. 1. Scheme of the arrangement. E = electrodes; I = rotating interrupter; P = potential divider; B = current source; K = key. The speed variator and electrical motor are not represented

even with higher frequencies, because the threshold, with fast interruptions, can be at the most twice the threshold for a continued stimulus (16).

We took the C. F. F. to be that frequency of the intermittent electrical stimuli when the subject perceived only one flash of short duration, at the beginning and at the end of the discontinued stimulus, which lasted around 3 seconds each time. The subjects could, after a short practice, very definitely differentiate phosphenes, which flickered, at least at the beginning, from fusion, i. e. from the appearance of one short flash. In ascertaining the C. F. F., we also used the method of constant stimuli, so that the subjects were not in a position to know in which direction changed the frequency of the stimuli.

The intravariability of the values of the C. F. F. on various days was different for the different subjects, and varied from 3.9 to 8.3 per cent. The intravariability of each subject was small during the same experiment. After the measurements of the C. F. F., the subjects were tired by physical and mental work respectively. Physical work consisted of a step test, where the subject jumped onto and from a 45 cm. bench,

at a rhythm of 25 steps per minute. That work went almost near the limit of tolerance, and lasted 9–20 minutes, according to the subject. The mental work consisted of adding pairs of two digit numerals continuously through 90 minutes. The numbers were dictated by the experimenter as fast as the subject could give answers.

As the subjects stated, the one as well as the other form of work caused distinct fatigue. After the step test, fatigue, both diffused and localised in the muscles of the legs, was vigorous, and the subjects felt traces of this work two days after the experiment. Adding by heart required much effort in the second half of the work period, and at the end, the subjects complained of headache, sleepiness, and general lack of volition.

After this work, tke C. F. F. was again ascertained, and then the absolute threshold. This measurement lasted around 25 minutes.

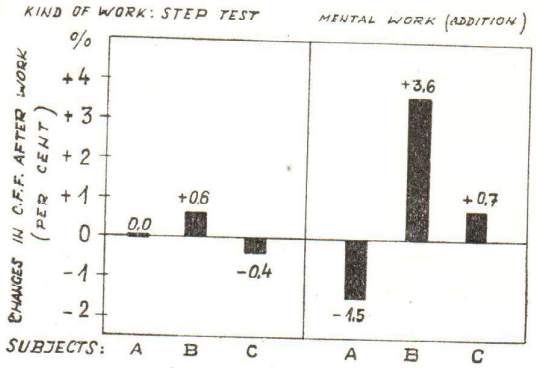

Fig. 2. Changes in C. F. F. after physical and mental work in per cent of initial values

Besides these experiments, we measured thc C. F. F. during a period of loss of sleep, which lasted 24 hours. All experiments were carried out on 3 subjects.

RESULTS

The values of the C. F. F. before and after work are given in table 1. Each result is the average of 10 series of measurements. Besides that, the table shows the standard deviations, the differences between the means of the C. F. F., and the reliability of the differences.

As can be seen, fatigue, provoked either by physical or mental work, does not influence the C. F. F. of electrical stimulations of the eye. The differences obtained are of different signs, and are not statistically significant *(Fig. 2)*. Similarly, neither are the differences between the thresholds significant.

Table 1.

The C. F. F. before and after physical and mental work

Subject	Before work		Kind of work	After work		Difference in cycles/sec.	D/σ_D
	C. F. F.	σ		C. F. F.	σ		
A	43,0	2,54	step test 9 min.	43,0	3,07	0	0
	47,9	3,66	addition 90 min.	47,2	2,42	— 0,5	0,34
B	52,7	4,25	step test 12 min.	53,0	4,49	+ 0,3	0,15
	49,7	3,01	addition 90 min.	51,5	1,95	+ 1,8	1,51
C	52,4	5,73	step test 20 min.	52,2	4,01	— 0,2	0,09
	58,6	5,78	addition 90 min.	59,0	3,72	+ 0,4	0,17

We had an opportunity of ascertaining that even considerably longer physical work did not influence the C. F. F. of phosphenes on two athletes, who ran 25 kilometers in 2,5 hours, with rate of climb of 700 meters. With both of them, the C. F. F. was even increased after the run, but that rise does not go beyond the limit of the normal variability of the results.

In comparison with the values of the C. F. F. of electric phosphenes, which some other authors obtained (17), and which go up to 120 stimuli per sec., our values are considerably lower. That is so, because we worked on a relatively low level of intensity, and as it is known, the C. F. F. of electric phosphenes increases with the increase in the intensity of the stimulus (18).

In investigating the influence of a period of loss of sleep on the C. F. F. of electric stimulation, we made 4 measurements on 3 subjects: the first day at 11. A. M. and 6 P. M., and the second day at 2,30 A. M. and again at 11 A. M. Before each measurement of the C. F. F., we first measured the threshold, and, by using the intensity which was thrice the threshold just found, we ascertained the frequency of fusion. Therefore, differing from the previously mentioned experiments, in which we measured the C. F. F. before and after work on the same intensity level, in these experiments we changed the stimulus intensity proportionally with the variations in the sensitivity. But, as these variations in the treshold values were small, the intensities of the stimuli did not differ much in the successive measurements. These experiments were carried out by the method of limits.

Figure 3 and table 2 show the obtained results. Each value is the average from 16 series of measurements.

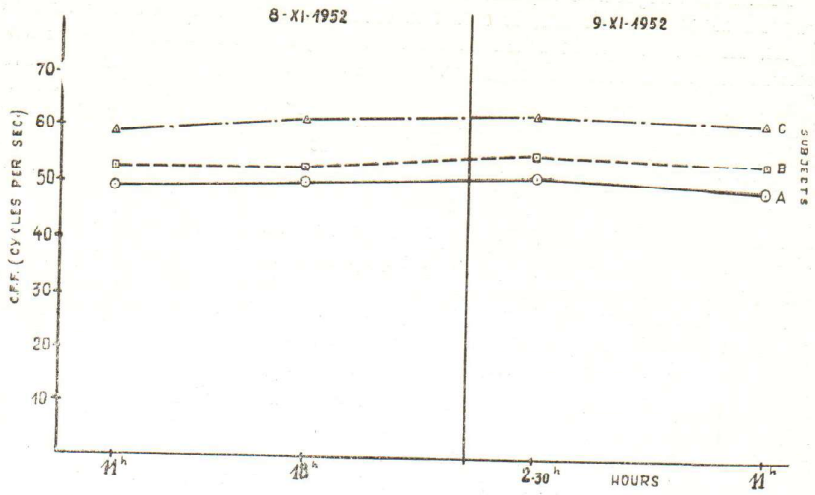

Fig. 3. Values of C. F. F. during loss of sleep

As it is seen, neither the loss of sleep causes significant change in the C. F. F. of electrically provoked phosphenes, although the subjects felt definitely fatigued near the end of the experiment. The differences in the C. F. F., which we obtained during the 24 hours interval are of a positive sign, which points to an increase rather than to a decrease of the C. F. F. However, even these differences are not statistically quite significant.

Table 2.

The C. F. F. in the course of the 24 hours of loss of sleep

Subject	Nov. 8 11 A. M.		Nov. 8 6 P. M.		Nov. 9 2,30 A. M.		Nov. 9 11 A. M.		Differences (D) in the C. F. F. in the 24 hours interval	D/σ_D
	C.F.F.	σ	C.F.F.	σ	C.F.F.	σ	C.F.F.	σ		
A	48,9	1,4	50,1	1,2	51,5	1,7	49,5	2,4	+ 0,6	0,84
B	52,7	2,36	53,0	2,0	55,6	2,4	54,1	2,6	+ 1,4	1,55
C	58,8	3,0	61,6	2,5	62,7	2,6	61,6	3,7	+ 2,8	2,26

DISCUSSION

From its subjective aspect, that, which we called the fusion of interrupted electrical stimuli, is not the same as the fusion of the flash of light. In the adequate stimulation of the eye, the flicker passes into a continual sensation of light, which lasts as long as the stimulus. Contrary, in electric stimulation, intermittent phosphenes are present for the duration of the stimulus only when frequencies of stimulations are relatively low. As the frequency increases the initial flicker becomes shorter and shorter, until it is at last reduced to only one short-lived phosphene, at the beginning and at the end of the stimulation, i. e. at the closing and opening of the electric circuit. In the field of electric phosphenes, the so-called C. F. F. represents that frequency of the stimuli, upon which the sensitive tissue can react only in the moment of a rapid disruption of the initial equilibrium. But even this state points out some functional characteristics of the nervous tissues, which, as we have seen, do not change in the state of fatigue.

Therefore, if new experiments prove, that the C. F. F. of *adequate* stimuli of the eye is decreased in the fatigue stage, then that decrease should be attributed to the changes in the *peripheral retinal structures*. In that case, the C. F. F., as a test of fatigue, would only show the functional state of the retina, i. e. the specific fatigue of the eye, and not the general condition of the central nervous system.

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SADRŽAJ

MOŽE LI KRITIČNA FREKVENCIJA FUZIJE ISPREKIDANIH ELEKTRIČNIH PODRAŽAJA OKA SLUŽITI KAO TEST UMORA

Ispitivanje umora znatno je otežano time, što se nijedan fiziološki, biokemijski ni psihološki test, koji se dosad u tu svrhu upotrebljavao, nije pokazao dovoljno pouzdanim. Fiziološki i biokemijski testovi ne zadovoljavaju u potpunosti zbog toga, što različite kemijske promjene u organizmu, promjene u funkciji različitih organa i nervne aktivnosti u toku dužeg rada nisu uvijek u korelaciji, pa njihovo jednostrano testiranje ima relativno slabu dijagnostičku vrijednost. Nedostatak psiholoških testova za ispitivanje funkcionalnog stanja najviših živčanih struktura opet je u tome, što rezultati mogu biti znatno pod utjecajem motiviranosti ispitanika. Nešto su pouzdaniji esteziometrijski psihološki testovi, jer pri ispitivanju osjetnih funkcija ispitanik ne može kontrolirati svoje rezultate niti može na te rezultate znatno utjecati pojačanim zalaganjem. Među takvim testovima u posljednje se vrijeme kao test umora mnogo proučava test kritične frekvencije fuzije (k. f. f.) isprekidanih podražaja svijetla. Taj se test sastoji u mjerenju one frekvencije svjetlosnih podražaja, koja upravo izazivlje kontinuirani vidni osjet. Neki autori smatraju, da se tim testom može ustanoviti funkcionalno stanje živčanog tkiva, pa da je prema tome umor, koji tim testom mjerimo, centralne prirode. Ali rezultati, do kojih su došli različiti ispitivači, nisu jednoznačni: dok su neki našli smanjenje k. f. f. u stanju umora, drugi nisu mogli ustanoviti nikakve promjene.

Budući da se osjet svijetla može izazvati i *električnim* podraživanjem oka (t. zv. fosfeni), autori su se odlučili za ovaj oblik ispitivanja, jer tu periferne promjene u funkciji samog vidnog aparata ne mogu utjecati na rezultate.

S pomoću pravokutnih udaraca istosmjerne struje, koji su se mogli davati različitom frekvencijom, ispitana je na 3 ispitanika k. f. f. električnih fosfena u stanju odmore-

nosti i u stanju većeg tjelesnog, odnosno intelektualnog umora. Tjelesni se rad sastojao u radu na step testu gotovo do granice izdržljivosti (ritam 21 na minutu kroz 9 do 20 min.), a intelektualni rad u zbrajanju napamet parova dvoznamenkastih brojeva kroz 90 minuta. Osim toga mjerena je k. f. f. i u toku bdijenja, koje je trajalo 24 sata.

Rezultati su pokusa pokazali, da k. f. f. isprekidanih električnih podražaja nije u stanju umora usporena. Razlika nije nađena čak ni kod dva trkača, koji su u 2,5 sata pretrčali 25 km s usponom na visinu od 700 m. Isto tako nije ni bdijenje izazvalo nikakvu značajnu promjenu u k. f. f., iako su se ispitanici osjećali izrazito umorni.

Prema tome test kritične frekvencije fuzije električnih podražaja oka ne može služiti kao test umora. Ako novi pokusi potvrde, da je u stanju umora usporena k. f. f. *adekvatnih* (svjetlosnih) podražaja oka, onda to usporenje treba pripisati promjenama u perifernim retinalnim strukturama, t. j. specifičnom umoru oka, a ne promjenama u općem stanju centralnog nervnog sistema.

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