Arh. hig. rada, *19* (supl. 1) (1968) 27.

PSYCHOPHYSIOLOGICAL STUDIES OF SOME ASPECTS OF FATIGUE AND REST

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The basic problems investigated at the Laboratory of Psychophysiology of Work can be divided into several fields: (I) Testing and assessment of fatigue, (II) Mechanisms of fatigue, (III) Efficacy of various forms of rest, (IV) Effect of psychological, physiological, and pharmacological stimulators on fitness for work, (V) Electrophysiological studies, (VI) Psychophysiology of senses, and (VII) Motivation and working activity.

I. TESTING AND ASSESSEMENT OF FATIGUE

One of the basic conditions for the study of fatigue is the possibility of the early detection of symptoms in which fatigue manifests itself. As in spite of a great many attempts there are not as yet any reliable, generally acceptable tests for measuring fatigue, we have conducted several investigations with a view to elucidating the cause of this failure and possibly filling the gap by a new approach to the problem.

The effect of physical and mental fatigue was studied in relation to sensory and perceptive functions, psychomotoric functions, and some electrical changes in the organism (1).

In the field of sensory and perceptive functions our studies related to changes occurring under the influence of fatigue in the acuity of stereoscopic vision (2), in dynamic visual accomodation, in the critical frequency of interrupted electrical stimulation of the eye (3), in the rate of adaptation to flickering, in the perception of aftermovement, in the perceptive changes of non-stable structures, and in perceptive illusions.

In the field of psychomotoric functions the effect of fatigue on the speed and accuracy of visualization (4), the accuracy in the reproduction of arm movements and stability of pressure (5), and the amplitude of the arm after-movement in unloading (6) was examined in detail.

Effects of fatigue and effort as are reflected on the EEG and EDR were analysed as well (1, 7).

Although these studies have given some interesting information on perceptive and psychomotoric activity in the state of rest and fatigue, they have resulted in no discovery of a valid test of fatigue. The results obtained only confirm what have already been known, i. e. that

changes in the function of isolated systems cannot be a reliable test of fatigue. Changes produced by fatigue in isolated systems do not develop in every subject in the same direction, nor is there any substantial regularity in their relation to the intensity and duration of effort.

As various physiological tests have also failed in detecting fatigue that accompanies or results from normal occupational activity, the next attempt was to verify the reliability and validity of subjective evaluations of fatigue. Unlike various objective symptoms considerably varying from one kind of fatigue to another, the feeling of fatigue is a sort of common denominator for all varieties. Besides, the feeling of fatigue reflects the structure of changes having occurred in the organism, changes that taken separately are almost subliminal and for this reason unusable in early detection. Finally, motivation, satisfaction with work, attitude towards work, and even various neurotic symptoms provoked by work are connected with the intensity and frequency of the experience of fatigue rather than particular and variable physiological changes in the organism.

The first investigation on the subjective evaluation of fatigue aimed at checking if the subjective experience of fatigue produced by a certain occupational activity was really connected with some objective characteristics of the worker's job and his behaviour (8). This study was carried out by means of a special questionnaire and some objective indicators of the worker's success and behaviour. The results have shown that the main traits of the workers that by their own judgement get tired at work considerably varies in a great many dimensions from the main traits of the workers that do not get tired at work. These logical associations indicate that from the data on the feeling of fatigue alone it is possible to predict some subjective and objective repercussions of fatigue. The application of a similar questionnaire in school children has confirmed the practical usefulness of such an approach (9).

Another attempt towards checking the usefulness of the subjective evaluation of fatigue lay in comparing such evaluations with the duration of static effort and summed muscular electrical activity (10). The results have shown that subjective judgements of fatigue as the function of the duration of static effort mainly follow the potential positive acceleration function, which is in accordance with our knowledge of the accumulation of fatigue.

Electromyographic analysis of muscular activity in the course of static effort has given a similar result. The average curve of the summed EMG as the function of the duration of effort has the same course as the average curve of the subjective evaluation of fatigue and can be expressed by the analogous formula with almost the same exponent of increase.

A relatively good inner coherence of subjective evaluations of fatigue and their paralellism with the duration of work and the summed EMG have stimulated us to continue verifying the subjective metric of that kind and trying to improve them.

In further work the method of residual possibilities and the summed EMG in the course of recovery were used as criteria for the validity of subjective rating (11). The evaluation of fatigue was somewhat improved in that this time the borderline values of the scale were numerically defined and known to the subject. The disappearance of traces of fatigue in the course of rest – followed on the basis of subjective rating, the ratio between the duration up to the limit of endurance of the second and first effort, and restitution in the summed EMG – has shown an identical general course in all these three cases, assuming the form of a curve of negative acceleration. The only difference was actually in that in the first period of rest the degree of fatigue expressed by subjective rating was »overrated« and after a longer rest »underrated« in relation to the remaining two criteria.

II. MECHANISMS OF FATIGUE

Different, often contradictory theories of the site and immediate causes of fatigue have induced us to conduct some investigations that directly or indirectly also included the analysis of the mechanisms of fatigue.

Studying the effect of loading on work output and recovery rate in static work (12, 13) a significant difference was observed in the recovery rate of functional capacities after light or heavy loading. The time needed for full recovery after work with heavy loading is several times shorter than needed for full recovery after light loading. Differences in endurance, and in recovery rate in particular, suggest that in the field of static work the mechanism of fatigue is not uniform. The fatigue produced by intensive static effort appears to be in the first place the effect of changes in the nervous system and neuromotoric synapses, while the fatigue produced by static effort with light loading appears to be mostly due to local chemical changes in active muscular groups.

Further investigations have shown that the mechanism of fatigue produced by other forms of activity is not uniform either and that, in addition to intensity, it depends on the duration of work, the kind of work, and specific characteristics of the subject. At the root of complex activities such as human work there are complex structures resulting from a dynamic integration of particular systems. In the course of work, if activity lasts long or is intense, the complex structure starts to disintegrate. The basic characteristic of almost all varieties of fatigue appears to be a partial disintegration of the structure best adapted to the task. The weakening of normal integration, along with a more labile integration on another level, results in the relative independence of particular mechanisms, which explains why in the state of fatigue the function of isolated mechanisms may sometimes even improve (14).

This general concept of fatigue was submitted to direct verification in the field of intellectual work (15). A battery of mental tests was applied in two groups of subjects: the control group was tested in the state of rest and the experimental one in the state of fatigue. As regards average results in the tests and the variability index there was no difference between these groups. However, changes were observed in correlation between the tests. The analysis of intercorrelation profiles has shown that in the control group all the tests of the same or similar factor structure formed a uniform profile, while the logic of the profiles in the experimental group was substantially disrupted. This means that the factor structure underlying intellectual activity changes under the influence of fatigue.

Disintegration and new integration on other levels are primarily due to changes in the nervous system. Local changes, varying a great deal in relation to the kind, duration, and intensity of work, appear to have only an indirect role in the genesis of fatigue.

This concept was corroborated by the result obtained in a study on the speed of word recall in rested and fatigued state (16). Restricted associations relating to recalling proper names were equally numerous and followed the same course of »discharge« in both situations. This result, seemingly contradicting the well-known fact that in the state of fatigue there are certain difficulties in the actualization of certain data, may be explained by the greater independence on the part of isolated mechanisms in the state of fatigue.

III. EFFICACY OF VARIOUS FORMS OF REST

The efficacy of human work, if considered for a longer period, depends not only on the degree of mobilization of working synergies in the course of work but also on the degree of recovery in the periods of rest. For this reason the studies of the efficacy of rest have its practical justification.

In the field of static work the effect of the number and length of rest pauses on work output was investigated (17). The results have shown that in static work, too, it is better, as regards work output, to divide the total duration of rest into a larger number of short pauses than into a smaller number of longer pauses.

The accumulation of fatigue in the course of static work and the recovery rate after static efforts of various duration were investigated by the method of residual possibilities (18). These experiments have shown that recovery is disproportionally the quicker, the shorter the effort preceding it. The recovery rate allowed the assessment of the accumulation of fatigue in the course of work which proved to follow a curve of pronounced positive acceleration.

As regards the form of rest, comparative studies were performed in the field of dynamic work in order to check the effect of passive and relative rest on work output, pulse rate, and the subject's feeling of comfort (19). The work was stimulated by the observation that contrary to what would be expected on the basis of laboratory findings, the workers often prefer a longer rest to a larger number of short rest pauses. This preference was supposed to have a certain objective justification, because each transition from the state of rest to the state of action is likely to require a re-mobilization of working synergies.

Unlike the so-called active rest of the Sečenov type, the type of rest used in the experiment was relative rest consisting of the continuation of the same activity but with a diminished loading. The results have shown that the total work output was the highest when work was interrupted by relative rest pauses, the second highest when work was carried out with sporadic passive rest pauses, and the lowest when work was carried out continuously up to the endurance limit. In spite of a higher work output in the situation when rest was only relative, in the maximum pulse rate and the cardiac debt after the cessation of work there was no difference between the working situation with blank pauses and the situation with relative rest pauses. Moreover, the subjects felt more comfortable when changing from partial to full activity than when changing from blank pause to activity. A higher economy of relative rest may be due to a smaller variation in the level of working synergies, a better blood circulation, and a higher neuromuscular co-ordination stability.

Experiments on rats were made to study the effect of amphetamine on the recovery rate (20). The work hypothesis was that pharmacological stimulators that are useful in the course of work might in the course of rest interfere with the process of recovery. In the experiment rats were made tired by a series of repetitive work (swimming), each time up to the end of endurance. This was followed by a 3-hour rest. At the beginning of rest the experimental group was given amphetamine and the control group the physiological solution. The degree of recovery was tested at the end of rest by a series of new efforts. In spite of a higher motoric excitement of the rats treated with amphetamine, their recovery in the course of a 3-hour pause was just as good as that of the rats from the control group.

IV. EFFECT OF PSYCHOLOGICAL, PHYSIOLOGICAL, AND PHARMACOLOGICAL STIMULATORS ON WORK CAPACITY

As today, in combatting fatigue and to increase working effect, various »stimulators« have increasingly been used, a series of experiments were conducted with a view to making out to which extent stimulators might affect physical working capacity and whether such stimulation was physiologically justifiable.

The duration of static effort up to the endurance limit and energy expenditure during and after effort were used as criteria of the efficacy of psychological stimulators (21). Static effort was made in two situations. In the situation of less intense motivation the subject was stimulated to work only by being instructed to endure as long as he could. In the situation of more intense motivation the subject competed with himself and with other subjects. The results have shown that in the situation of higher motivation the work output was considerably higher and the energy expenditure, in the same periods of effort, significantly lower. After the cessation of effort there was no difference in oxygen debt. Thus, a positive effect of psychological stimulation does not appear to be the result of a repressed feeling of fatigue or work in a physiologically unjustifiable situation but is likely to be due to some dynamogenic changes in the vegetative nervous system allowing the carrying out of work in a more economical way.

In another study the effect of psychological stimulation was analysed by measuring the residual degree of fatigue after the effort performed with lower or higher motivation (22). In the condition of higher motivation static endurance was increased, while the degree of fatigue equalled that after a shorter effort performed in the condition of lower motivation. When in the experiment with higher motivation the subject's effort was interrupted at the moment corresponding to his maximum endurance in the situation of lower motivation, fatigue was proved to be lower than after work without any additional motivation.

»Contrast«, i. e. a short-lasting preceding effort on a considerably higher intensity level than the effort studied, has proved a successful psychophysiological stimulator. A rapid transition from higher to lower loading expresses itself not only in a subjective underrating of the lower effort but also in an actually increased working capacity on this lower intensity level.

A study related to the phenomenon of contrast in which the maximum static endurance on a certain low level in normal conditions was compared with the maximum endurance on the same level when this activity was preceded by a short effort with a considerably higher loading (23). It has been observed that the preceding intense effort, provided its duration is not too long, significantly increases endurance with a low loading. However, when changing from the previous effort of low intensity to a more intense work, the subject overrates the second effort and his endurance at this higher level is diminished. The positive effect of »contrast« in unloading is probably connected with a rapid mobilization of working synergies which, by adjusting the organism to intense effort, allow a more economical work, at a lower level.

A positive effect of contrast was confirmed by the analysis of the results obtained in iron ball throwing (24). A group of subjects being »warmed up« by throwing a heavier ball prior to the contest with the

normal-weight ball, obtained significantly better results in the standard--ball throwing than a group of subjects being warmed-up by throwing a ball that was lighter than the normal one.

Certain physiological stimulators, such as hyperventilation and washing the face in cold water, the efficacy of which in suppressing fatigue is quoted in the literature, have proved hardly effective at least in the field of static endurance (25).

The studies of the effect of pharmacological stimulators on physical endurance in static and dynamic work have been carried out in humans and animals.

The analysis of the effect of amphetamine on the economy of static work has shown that the organism pays for a somewhat higher output under the effect of amphetamine by an increased oxygen debt (26). This indicates that under these conditions the organism does not work more economically as is case in psychological stimulation but increases the work output at the expense of its reserves.

Extensive studies (27) in the field of static and dynamic work with various sympathomimetics and sedatives have shown that in well-motivated and rested subjects the effects of these drugs is negligible. Under such conditions the mere natural mobilization of working synergies is sufficient for the organism to adjust itself to increased working requirements. Pharmacological drugs somewhat increase physical endurance only when used in the phase of relative fatigue, but even this positive effect is probably due to the euphoric or analgetic effect of the drugs rather than the actual bettering of inner physiological conditions. As man's normal physical activity is regularly carried out on a submaximum level, the administration of various drugs to increase physical endurance is objectively useless, and with regard to the risk of habit forming, overdosage, and interference with sleep, it is quite certainly harmful as well.

These results are in agreement with those obtained in rats (20). In a series of repetitive efforts relating to swimming up to the limit of drowning, the rats given amphetamine showed no higher degree of endurance than the control group. Sympathomimetics appear to produce only superficial symptoms of increased excitability of the sympathicus and no complete natural mobilization of working synergies as is brought about under the influence of the sympathicus in situations critical for the organism.

V. ELECTROPHYSIOLOGICAL STUDIES

Electrophysiological methods have been used in the study of cerebral activity in prolonged intellectual work, muscular activity in static work, and some phenomena in the field of electroergography and electrostatography.

Electroencephalographic studies have been carried out with a view to following changes in the alpha waves in prolonged intellectual work and the behaviour of alpha waves in blocks i. e. involuntary short rest

pauses occurring in the course of continuous intellectual activity (28). Evidence has been obtained that in the initial working period the alpha index rapidly decreases, then this reduction is slowed down until it reaches the lowest value, after which this index tends to go up. After the cessation of work the alpha index increases, but a longer period is needed for it to reach its initial value. These changes may be explained by the opposite effect of exercise dominating the first phases of work and fatigue which is more pronounced the longer the effort. No difference was observed between the alpha index in the course of work and that in blocks. This fact speaks against Rohracher's theory that alpha waves reflect restorative metabolic processes.

When alpha waves appear in the course of intellectual work, they are of a somewhat higher frequency and reduced amplitude. The alpha index is in a negative correlation with the intensity and extension of cortical activity but also emotional tension may affect it (29).

Investigating the effect of steady and intermittent light on the alpha index it has been found that following the initial pronounced depression the alpha rhythm gradually recovers in the course of stimulation, and this appears to occur the more rapidly the higher the frequency of intermittent stimulation (30).

In the field of electromyography the studies have been focused on the analysis of the increased summed electromyogram in the course of static effort carried out to the limit of endurance (31). The increase of the summed electromyogram which follows the curve of positive acceleration ($\Sigma EMG = k \cdot t^{n>1}$) has been interpreted as the result of the recruitment of new motor units the activity of which overcompensates the fall in the frequency and amplitude of the action potentials of previously active motor units. Assuming that the motor units of a muscle represent a certain population in which the magnitude of the stimulus threshold is normally distributed, the curve of the increase of the ΣEMG in the course of work may partly be assimilated to the curve of the integration of motor units. The results obtained in experiments on restitution indicate a long persistence of ΣEMG changes. When a static effort is repeated after a rest pause not long enough for fully recovery, straight from the beginning of the new effort a larger number of motor units are engaged, and also their recruitment in the course of work is quicker than when the subject is rested. However, as the final ΣEMG level of the second effort is not higher than the correspondent level of the effort preceding it, it is little likelihood that in these conditions the muscle should behave as if it was only more loaded straight from the beginning *(Scherrer)*. The constancy of the final level suggests that in both the rested and the fatigued muscle, under constant objective loading, there is probably also a constant number of motor units that at the end of effort may be engaged in a simultaneous activity. When this number is achieved, it is no longer possible to persevere in work. Contrary to the opinion of some authors *(Bartoshuk, Eason)*, the EMG gradient does not appear a direct

measure of the intensity of the subject's motivation; what it reflects in the first place is the difficulties the subject is facing in fulfilling his task, and these difficulties may affect his motivation in quite different ways.

In electroergographic experiments the effect of the intensity of electrical stimuli on work output has been investigated (32). It has been found that the increase of the stimulus intensity first produces a rise in work output up to a certain maximum, and then it goes down again. As in the experiments electrical stimuli of high frequency were applied, the hypothesis of *Vedenski's* inhibition could only partly explain the existence of an optimum in the electroergograms obtained.

In further experiments the effect of superposed electrical stimulation on the voluntary ergogram and voluntarily provoked isometric contractions there is also a simultaneous electrical stimulation of the motor point of the active muscle, the output effect of this combined ergogram is lower than when only voluntary contractions are used. Experiments with short superposed electrical stimuli during submaximum voluntary static contraction have shown that at the beginning these electrical stimuli somewhat increase contraction and later significantly lower it. It has been assumed that additional electrical stimulation, at least in later phases of work, decreases work output because of its growing effect on extensors which, owing to the previous activity of flexors, have come into a state of increased excitability.

VI. PSYCHOPHYSIOLOGY OF SENSES

In the field of sensory reactions and perception the studies have been conducted in relation to various perceptive determinants, adaption to flickering, the effect of lighting intensity on intellectual work, and – in collaboration with the Laboratory for the Physiology of Senses in Paris – the effect of different rates of the stimulation intensity increase on the absolute and differential hearing sensibility.

Among factors that may affect the accuracy and speed of perception of differently constructed instrument scales, the effect of practice was examined (34). The evidence obtained have confirmed the work hypothesis that the essential elements underlying perception change in the course of exercise and that after a certain amount of practice the correspondence of objective data and the perceptive content is based on a type of information other than that existing at the beginning.

Within extensive studies of the effect of subfusional and suprafusional frequency of intermittent light on the visual function, the phenomenon of adaptation has been studied in detail (35). In adequate eye stimulation the adaptation on flickering is relatively slow and can be achieved only within narrow limits. On the contrary, in electrical intermittent eye stimulation the adaptation range is considerably wider. A preceding eye stimulation by different subfusional light frequencies decreases the critical frequency of the fusion. The results obtained support the hypo-

thesis that a quick adaptation to intermittent phosphenes is related to inhibition in the retinal nervous elements, while the adaptation to light flickering might be the results of the worsened condition of the visual cortex. Discontinuous excitation by light, contrary to normal continuous stimulation, prevents the development of preventive inhibition in centres, which results in the decreased functional capacity of visual centres.

The results obtained have been corroborated by further studies in which the intensity of intermittent light varied (36).

In the two studies attention was focused on a new factor that might affect the function of sensory organs – the increase rate of the stimulus intensity as the function of time (37, 38). The results have shown that the absolute hearing threshold does not change as the function of changes in the rate of the increased stimulus intensity. In adequate stimulation of the hearing receptors there is no subliminal adaptation. On the contrary, the possibility of distinguishing sound signals on the sound backgroud is the weaker the slower the change in the intensity of the supraliminal stimulus. As in normal hearing conditions differential sensibility is of importance, the study of dynamic differential sensibility may be of special significance in the determination of the functional hearing capacity.

A dynamogenic effect of light has been analysed in intellectual work of school children (39). It has been observed that the quantity but not the quality of work output increases with the increased light intensity. However, a more intense lighting did prove to have a favourable effect on the motivation and the feeling of comfort of the school children examined.

VII. MOTIVATION AND WORKING ACTIVITY

The studies carried out in the field of motivation have comprised investigations concerning the effect of competition on work output, the hierarchy of motivation incentives absenteeism, the degree of workers' participation in the life and the activity of their enterprise, and various methodological problems connected with the determination of dominant motives and attitudes.

The experiments in which the psychological structure of competition was changing have shown that only competition between the groups markedly not differing between themselves in their work output produces a positive effect on work output and its increase. However, a great difference in the results of competing groups reduces motivation and improvement in both the more efficacious and the less efficacious group. Competition develops only where there is, at least theoretically, a certain chance of victory for both sides, or else, instead of competition, there appear such unadapted forms of behaviour as rationalization, regression, depression, and aggression (40).

The analysis of absenteeism has shown that in the average number of absences there is no difference between sexes, but in women absences have proved to be longer. Older workers are absent from work less frequently than young workers. As regards family responsibility, single males have most absences, while in women the relation is different: most absences are observed in married women and women with children. This is due to the fact that in men the increased family responsibility results in the increased vocational efficiency and in women in the increased household efficiency (41, 42).

For investigating workers' attitudes a special test of informativeness has been developed. It relates to various relevant aspects of the life and functioning of an industrial establishment, from narrow aspects relating to the worker's working place, wages, promotion possibilities etc., to wide structures of political and national economy (43). The test was constructed under the assumption that informativeness, which can be checked, was a far more valid indicator of workers' interests and attitudes than their answers to direct questions or verbally declared attitudes.

The application of this informativeness test has shown that the degree of informativeness, in relation to various narrower or wider aspects of the life and functioning of the factory, is affected by age, length of service, and sex. It has been proved that on the basis of such a test it is possible to follow the dynamics of the workers' inclusion in the life and activity of the factory and to determine the dominant sphere of their interests, as well as the pattern of the broadening of this sphere (44, 45, 46).

To investigate the hierarchy of incentives at work a special questionnaire was constructed, based on the paired comparison technique. In addition, the questionnaire contained questions meant to reveal the degree of deprivation or satisfaction of workers as regards to what extent their different needs were met (47). The application of this questionnaire has shown that Yugoslav workers are motivated at work by economic and also ideological factors, by which the hierarchy of motives significantly changes under the influence of deprivation or satisfaction of certain needs.

A study related to the most appropriate way in which to apply a questionnaire and the effect of the kinds of application on fullness, consistency, and accuracy of answers (48). In view of these criteria, the so-called guided collective application proved most successful, the application in the form of an interview proved somewhere in-between, and the free collective application was found as the least successful way of inquiry.

To study the connotative meaning of concepts and attitudes, a new form of the semantic differential – a kind of graphic bipolar scales – has been drawn up (49). Application of the graphic semantic differential has proved to yield more sincere assessments of socially delicate

concepts and for this reason this method appears far more valid in attitude investigations than the verbal form. Moreover, denotative moments affect answers to a far lesser degree, and owing to a greater universality of graphic signs, this new form of inquiry may serve better than the verbal one in the crosscultural investigation of attitudes.

Most of the papers published relate to laboratory work. Yet many a result obtained could already be verified and applied in practice. This would certainly help increase productivity and make work itself more comfortable and easier for the immediate producer.

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