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REVIEW ARTICLE

Measurement of Fatigue in Industries

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Abstract: Fatigue of workers is a complex phenomenon resulting from various factors in technically innovated modern industries, and it appears as a feeling of exhaustion, lowering of physiological functions, breakdown of autonomic nervous balance, and decrease in work efficiency. On the other hand industrial fatigue is caused by excessive workload, remarkable alteration in working posture and diurnal and nocturnal rhythms in daily life. Working modes in modern industries have changed from work with the whole body into that with the hands, arms, legs and/or eyes which are parts of the body, and from physical work to mental work. Visual display terminal (VDT) work is one of the most characteristic jobs in the various kinds of workplaces. A large number of fatigue tests have already been adopted, but it is still hard to draw a generalized conclusion as to the method of selecting the most appropriate test battery for a given work load. As apparatus for fatigue measurement of VDT work we have developed VRT (Visual Reaction Test) and the Portable Fatigue Meter. Furthermore, we have presented immune parameters of peripheral blood and splenic T cells for physical fatigue.

Key words: Fatigue, Measurement, Industry

Introduction

Recent modernized industries have been characterized as technically innovated workplaces in working modes, working conditions and new methods for work, etc. Those are mechanized and automatically controlled jobs, a reduced numbers of workers, simplification, division and efficiency of the work, etc. Ergonomic viewpoints have become important in the relationship between man, machine and working environment. The General Guidebook on Industrial Health of Japan in 1998 reports a decrease in 8,557 that is 2/3 of patients with occupational diseases in compared to those of 10 years ago[1]. But an increase has been brought about in patients with low back pain caused by the working mode or working posture and with work-related diseases due to the progress of aging such as brain and heart diseases, and an increase in the number of workers suffering from anxiety, trouble and distress in life and in the workplaces. Diseases of workers are classified into four categories: (1) private diseases, (2) work-related diseases, (3) occupational diseases, and (4) accidental diseases. These are caused by not only by one but also by a number of factors. In the field of mental health, the discovery and the control of patients with mental disorders were the main subjects in the early stages. It has been pointed out that fatigue and cause analysis of mentally unhealthy and suitable working conditions are very important in preventing mental diseases.

Fatigue is caused by many kinds of factors in the workplaces. These are (1) overtime work, (2) problems following the reduction of working hours related to 5 days work in a week, (3) sudden changes in the working environment due to high-technological innovations such as automation and introduction of ultramodern techniques, (4) employment of middle-aged workers in the aging society, (5) problems of working hours for part-timers, (6) changes in work, personnel cuts, reconstruction of enterprises, etc., as countermeasures for economic depression. According to our survey on absenteeism among clerical workers[2], the most common cause was mental and physical fatigue caused by the busyness of their work, the second was the tangle of human relations in the workplace, and the third was changes in work (Fig. 1). It is also recognized that urgent countermeasures are needed to maintain the health of workers and to prevent work-related diseases. Establishment of these countermeasures and methods for evaluating industrial fatigue and stress are essential as well as to make clear the causes of fatigue and job stress.

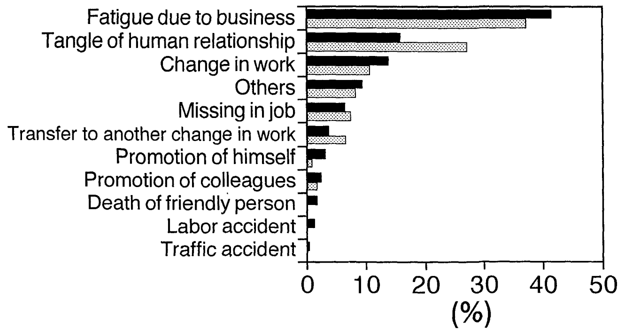


Fig. 1. Cause of absenteeism found from survey on 522 male and 90 female clerical workers

Characteristics of Fatigue in Modern Industry

Fatigue is a complex phenomenon resulting from various factors, and it manifests itself in various forms. To simplify the definition of fatigue, it is a state of being tired which is brought about by an excess of mental and physical work. This state results in lowering or an impairment of human functioning. Human functioning depends upon the physiological functions of many organs, as well as mental and physical behavior. In other words, fatigue as the combined manifestation of lowered mental and physical functions which result in decreased enthusiasm for work as well as decreased efficiency in work. Fatigue in the workplace has dual aspects, mental and physical, which interact upon each other so closely that to evaluate them separately is impossible, and it appears as a feeling of exhaustion, lowering of physiological functions, breakdown of autonomic nervous balance, and decrease in work efficiency. Industrial fatigue is caused by excessive workload, and it is dissipated or accumulates in relation to diurnal and nocturnal rhythms in life. Although fatigue is divided into acute, subacute and chronic states, mechanization in industry brought about by the revolution in technology has made a remarkable alteration in working posture. As a result of technical innovations in modern industries, working modes have changed from work with the whole body to that with the hands, arms, legs and/or eyes which are parts of the body, and from physical work to mental work.

Mechanized work in industry today is often simple repetitive hand work which requires an unnatural working posture. Work like this results in neuromuscular fatigue of the neck, arms, and hands, etc., and sometimes it is followed by central nervous fatigue in which the state is characterized as chronic fatigue of the whole body. This means that work is now concentrated in peripheral muscles and nerves and in sensory organs such as eyes. Mental and physical fatigue

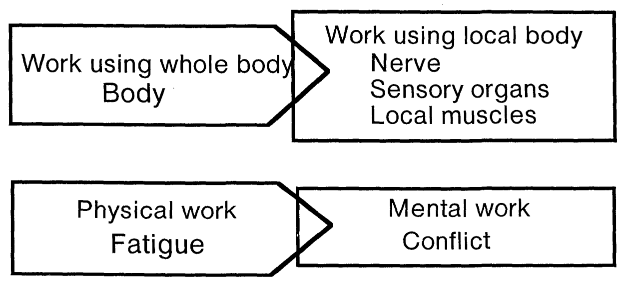


Fig. 2. Characteristics of work and stress factors in modern industry

as physical loads have changed to conflicts about how to operate new instruments, and each stress is accompanied by loads, restraints and the difficulty of the work as added loads (Fig. 2).

As an example, Computer work causes mental fatigue, neck and upper limb disorders, low back pain, etc., among the operators. Keyboard operation of computer terminals and computerized work require intense attention to the CRT and the keyboard. In visual display terminal (VDT) work, such complaints as neck, upper limb and low back pains include postural discomfort due to constrained work postures, neck, shoulder, and upper limb fatigue and pains due to repetitive upper limb motions, persistent eye strain brought about by a high visual load, irritating work procedures, and the feeling of being driven to work by controlled work methods. The unfavorable environmental conditions such as limited work space, disturbance by glare and reflection, low display contrast, and uncomfortable microclimate easily enhance these complaints (Table 1). Working a computer for a long time while suffering from these complaints causes a lowering of the higher nervous activities, particularly the concentration of attention: the result is a lowering of the ability to think, causing thoughtlessness and a large number

Table 1. Body burden evoked by VDT work

1. Physiological effects
    - static muscular load
    - dynamic muscular load
    - eye strain: visual fatigue
        - hardware method of CRT
        - visual function
        - ergonomics of work
        - environment
2. Psychological effects
    - mental stress
        - skillful level
        - technical level
        - contrast
        - habituation
        - liking
        - flicker
        - distinction
3. Fatigue
    - mental fatigue
    - physical fatigue
4. Individual variation

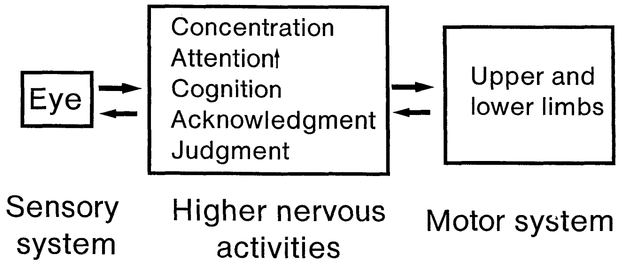


Fig. 3. Parts of human body in VDT work

of errors, decrease in work efficiency, and a diminution in the amount of work. VDT work due to office automation is shown in Fig. 3, which shows the importance of the cerebral cortex to control higher nervous activity in addition to the sensory and motor organs, that is, VDT work puts a load on the upper limbs and causes asthenopia, in addition to psychological mental stress.

It is well known that mental and physical restraint for the work become strong physical environmental stressors. The plasma corticosterone level on restrain stress of rats for 60 minutes in our experiment[3] increased significantly from the 15th minute and it reached its maximum level at the 60th minute. Zinc concentration in perfusate from the same rat hippocampus determined by a microdialysis method approached the maximum peak level at the 15th minute from the beginning of the 60-minute restraint stress, and decreased rapidly to the control level. Taurine and alanine levels in the same perfusate measured at the same time showed almost the same patterns. It was presumed that zinc in nerve cells was released from the cells with amino acids.

How to Evaluate Fatigue in the Workplace

In studying fatigue, the measurement of fatigue is a problem of incontestable importance. Fatigue manifests itself in various forms, and therefore cannot be measured or indicated by a single test or a change of only one function. Internal psychological and physiological changes in external environments impose a load upon a living body to the extent of causing excessive changes in physiological functions, the living body's internal stability is distorted and smooth functioning of its emotions and activities is hindered. A continued loss of such internal stability is felt as fatigue or stress. In such a case, even if a certain physiological function is heightened it indicates nothing more than the body's particular adaptive behavior, and therefore it often happens that a certain physiological level does not always agree with the amount of fatigue. This has raised the problem of selecting an appropriate test battery.

In our study, particular attention has been paid to the following points: fatigue is recognized as an overall state of the whole organism, even arising from the overuse of a certain organ or a muscle; diurnal fluctuation of physiological functions should be taken into account in evaluating the values, and the fatigued state should be assessed as an undesirable deviation from the homeostasis towards which all functions have a tendency. Fatigue is generally considered to have negative effects and is a premonitor of maladaptation or impairment of the organism in the working environment. On the other hand, it may play an active role as a manifestation of defense mechanisms. So a mere comparison of the test results before and after work is not sufficient to draw a conclusion. Thus the limit of allowable fatigue, that is, by what criterion over-fatigue should be discriminated and evaluated, has become the objective of our study. In this way, we shall be able to appreciate the undesirable negative factors relevant to such practical subjects as overloading, shift work, accident, climate, age, and vigilance, etc.

It is important in the assessment of fatigue that we should not only make physiological and psychological measurements, but also relate the findings to various factors which influence fatigue. This would make it possible to evaluate the grade of the obtained change in view of undesirable negative effects on health and well-being. In conclusion, fatigue should be evaluated by a multidisciplinary approach rather than simply measured. Nowadays, the main topics in the study of fatigue are evaluation of workload and work capacity, significance of fatigue tests, evaluation of muscular fatigue, subjective symptoms of fatigue, fatigue problems under automation, VDT work, indicators of nervous strain, and the practical application of fatigue study. Industrial fatigue is understood through changes in physiological functions. Physiological functions include mental or nervous function, autonomic nervous function, endocrinological function, metabolism, etc. These functions are lowered, disturbed or broken down by excessive workload. These phenomena can be measured by physiological and biochemical techniques.

Factors Which Influence Fatigue in the Workplace

1. Working mode

Lowering of work efficiency, decrease in work amount, decrease in accuracy and inferiority rates of workers, prolongation of the time for one cycle of work and a great variation and increase in mistakes are characteristic of industrial fatigue. The appearance of industrial fatigue differs according to the kind of work. The various kinds of work may be classified as (1) mental work, (2) physical work, (3) simple work, (4) monotonous work, (5) repetitive work, (6) natural or constrained working posture, (7) conveyor work, (8) clerical work, (9) VDT work, (10) work handling toxic substances, (11) work in injurious environments of noise, high temperature, etc. On the other hand, the kind of working modes in relation to accomplishment are classified into five categories; (1) work which mainly demands such higher nervous activities as memory, judgment, recognition, etc., (2) neurosensory work involving vigilance or operation, (3) simple repetitive work with movement of local muscles to push a button or to assemble parts of instruments, (4) dynamic muscular work to carry heavy substances or strike with a hammer, (5) mechanized clerical work such as key-punch or VDT work, since such work requires the maintenance of the same working posture.

2. Intensity of work

It is very important to remember that intensity of work affects the appearance of fatigue. It depends upon energy consumption, static or dynamic work, working speed, working accuracy, complexity of work, work which needs judgment or which is automatic, restrictiveness of work, attentiveness to work, movement of workers requested for working posture, range of work station, individual work or team work, etc.

3. Superfluity of work

There are two kinds of superfluity in work: one depends upon the work environment and the other depends upon the working posture. For instance, the coefficient of a hot environment becomes greater than that of room temperature. The coefficient of restricted work in relation to working posture becomes greater than that of nonrestricted work.

4. Difficulty of work and body burden depending upon time

Difficulty of work plays a very important role in the appearance of fatigue as well as the intensity and superfluity of work. The difficulty of work depends upon using parts of the body, pedaling with the feet, the use of one or both hands, coordination of eyes and hands, requirements for handling, and resistance due to weight as reported by Mundel (1970)[4]. Generally the normal rhythm in life for man to work in the daytime and sleep at night. But shift workers are obliged to work at night. The circadian rhythms of crews in aircraft are remarkably confused by time differences. In our country, at the Night and Shift Work Research Committee of the Japanese Association of Industrial Health, index numbers for body burden by working time are divided into to overtime work after 5 o'clock pm and night work. The committee also suggests that the amount of the body burden should be designated as a different value for each work shift. And because other living conditions, such as nutritional intake, sleep and rest conditions, exercise, and recreation have an effect on labor, it is very important to grasp the whole picture of the 24-hour life cycle in analysing fatigue.

Methods for Measuring Industrial Fatigue

We have to understand the physiological characteristics of fatigue to measure or evaluate fatigue. But the difficulty is that we are never able to measure fatigue itself directly. We know, however, the consequences of fatigue and may be able to point out this or that symptom of fatigue, or at least to measure physiological as well as psychological indications relevant to these symptoms of fatigue. In this respect, there can be mentioned a number of indicators which are generally applied in fatigue research: such measures representing cerebral cortical activity level as EEG, channel capacity or perceptual threshold such as flicker fusion frequency, some indications of vegetative functions, biochemical variables relevant to metabolic changes or to endocrine regulation, motor skills and others. Those tests which have been advocated for fatigue measurement can be classified from the viewpoint of methodology into the following 6 categories: (1) questionnaires on subjective feelings of fatigue, (2) psychological tests, (3) neurophysiological tests, (4) biochemical indexes, (5) physiological tests, and (6) autonomic nervous function tests. Some of the commonly used tests are: (1) the test for subjective symptoms of fatigue which was designed by the Industrial Fatigue Research Committee of the Japanese Association of Industrial Health. (2) Psychological function tests such as (a) the blocking test, (b) Kraepelin test, (c) dot counting method, (d) measurement of perception time, (e) Roken amefuri erasion test, and (f) anticipation reaction of speed, etc.; (3) Neurophysiological function tests by means of (a) electroencephalography, (b) sensory evoked response, (c) reaction time, (d) galvanic skin reflex, (e) aesthesiometry, (f) measurement of flicker fusion frequency, (g) target aiming function test, (h) eye movement, (i) visual tracing reaction test, etc.; (4) Physiological function tests of (a) muscular strength, (b) respiratory and circulatory functions, (c) heart rate, (d) near point distance, etc.; (5) Autonomic nervous function tests such as (a) adrenaline test, (b) atropine test, (c) mecholyl test, (d) cold pressor test, (e) Czermak test, etc.; (6) Biochemical blood and urinary indexes of (a) urinary excretion of protein, sugar, urobilinogen, creatinine, Donaggio reaction, Ogawa's colloid reaction, electrolytes, 17-ketosteroids, 17-hydroxycorticosteroids, catecholamines, uropepsin, etc. (b) eosinophilic leucocytes, total gravity of blood, hemoglobin content, serum proteins, blood sugar, etc. (c) other analyses of such factors as salivary pH, liver functions, renal functions, etc.

As indicated above, a large number of fatigue tests have already been adopted, but it is still hard to draw a generalized conclusion as to the method of selecting the most appropriate test battery for a given work load. For studies on fatigue, three requisites essential to fatigue evaluation are proposed: objectivity, reasonableness and logicality. Objectivity and reasonableness mean that at the present stage where there are no objective criteria for fatigue evaluation, the judgment on fatigue should be in agreement with the verdict rendered by our common sense, which is empirical in its own way. Logicality means being commensurate with the definition of fatigue and given physiological proof to the evaluation. Takahashi[5] in our laboratory studied the relationship between various kinds of fatigue tests in current use. There are a large number of them, but for our purposes, comparison was restricted to those which are in wide use because of their relatively understandable principles and clear mechanisms. Reactions of these tests to certain tasks were simultaneously observed and then compared. From a large amount of data on these fatigue tests during the past several years, The results obtained showed that there was no significant correlation except between CFF and E. CFF and aggulutination test, and E and KR. This means that in general the existing fatigue tests fail to give the same result. Therefore, it is essential that for the evaluation of fatigue, data obtained from a single fatigue test or a combination of fatigue tests having no correlation with each other must be considered with extreme care because in some cases the results will be useless. The important thing to keep in mind is what kind of function of ability a particular test indicates.

Some Representative Fatigue Tests Used in our Studies

1. Subjective symptom survey of fatigue

The test is given with a checklist of 30 items designed by the Industrial Fatigue Research Committee of the Japanese Association of Industrial Health[6]. It consists of A, B and C symptoms which are each 10 and 30 symptoms altogether, as shown in Table 2. The A symptoms are representative of "dull, drowsy (items 1–7) and exhausted feelings (items 8–10)", namely "a general feeling of incongruity in the body". B symptoms are all mental, and mean "decline of working motivation." Items 21–26 of C, concern a "specific feeling of incongruity in the body ". And items 27–30 represent "dysfunction of autonomic nervous systems". The frequency of complaints of fatigue is calculated with the formula: ("gross number of complaints in a group") × 100 / ("number of items × number of group members"). Both A and C symptoms are physical ones, but A is general, and C specific (sensory) and nervous (dysfunction of autonomic nervous system). In contrast to A and C, the symptoms B are purely mental, lacking a physical basis.

2. Analysis of fatigue from the standpoint of higher nervous activity

Characteristic of the subjective symptoms of fatigue shown above is the lowering of the arousal level in brain activity. It shows the regulation and balance of the interrelation between suppression and activation in the cerebral cortex, diencephalon, hypothalamus and reticular formation.

Table 2. Subjective feelings of fatigue

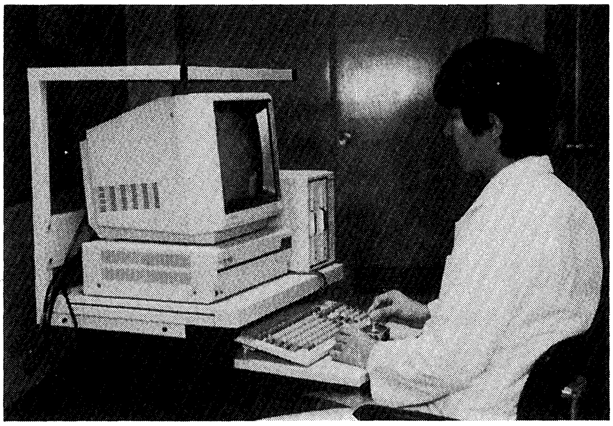
A: (1–10)	1. Feel heavy in the head	Dull Drowsy
	2. Feel tired in the whole body	
	3. Feel tired in the legs	
	4. Give a yawn	
	5. Feel the brain hot or muddled	
	6. Become drowsy	
	7. Feel strained in the eyes	
	8. Become rigid or clumsy in motion	Exhausted
	9. Feel unsteady while standing	
	10. want to lie down	
B: (11–20)	11. Find difficulty in thinking	Mental decline of working motivation
	12. Become weary while talking	
	13. Become nervous	
	14. Unable to concentrate attention	
	15. Unable to have interest in thinking	
	16. Become apt to forget things	
	17. Lack of self-confidence	
	18. Anxious about things	
	19. Unable to straighten up in posture	
	20. Lack of patience	
C: (21–30)	21. Have aheadache	Specific feelding of incongruity in the body
	22. Feel stiff in the shoulders	
	23. Feel a pain in the waist	
	24. Feel constrained in breathing	
	25. Feel thirsty	
	26. Have a husky voice	
	27. Have a dizziness	Dysfunction of autonomic nervous systems
	28. Have a spasm of the eyelids	
	29. Have atremor in the limbs	
	30. Feel ill	

Decrease in blood cerebral flow and diminution of amplitude in auditory evoked potential in the lowered state of concentration of attention and lowering of brain activity levels in fatigue are proved by the results of our experiments on the relationships between attention and cerebral ultrasonic attenuation, brain waves and auditory evoked potentials. The same findings are also recognized in fatigue resulting from physical work load. We therefore use the questionnaire on subjective symptoms of fatigue, target aiming function (TAF), flicker fusion frequency (CFF), visual tracing reaction(VRT), heart rate, electroencephalography (EEG), sensory evoked potentials (SEP), oxygen consumption, behavioral analysis, urinary and blood catecholamines and their metabolites of dopamine (DA), norepinephrine (NE), epinephrine (E), homovanillic acid (HVA) and vanil mandelic acid (VMA), plasma cortisol (PC) and erythrocyte enzymes scavenging superoxide anion: superoxide dismutase (SOD), glutathione peroxidase (GSH-PX) and catalase (CAT) as methods for measuring fatigue and stress.

3. Newly developed apparatus for fatigue measurement and immune reaction to fatigue

1) VRT (Visual Reaction Test)

Lately, with the extensive introduction of computers, the mode of labor has been significantly modified. In factories, manual work and inspection work which used to be done by human hands are now being done under automated control and inspection. In offices, more and more work is being handled by computers. In spite of these changes in the mode of labor, however, we still do not possess suitable instruments for measuring fatigue that answer the needs which these changes demand. In order to meet this situation we do the best we can by making combined use of such performance tests as Flicker, Accomodopolyrecorder, TAF, and Refractometer, etc. Although these tests have their advantages they also have their disadvantages. This situation makes it a matter of urgency to develop a method for accurately measuring the fatigue involved in visual tasks accompanied by hand and arm movements. For this purpose



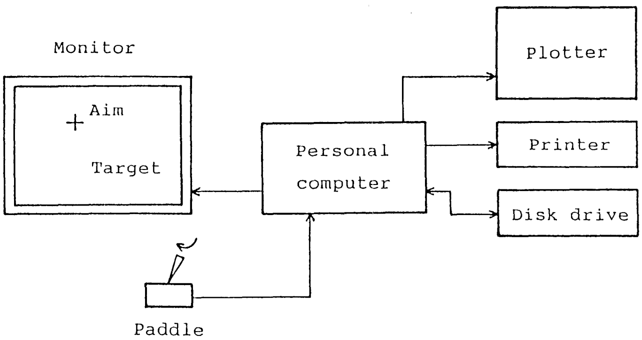


Fig. 4. Block diagram of VRT

we have developed the VRT (Visual Reaction Test)[7]. In this apparatus, a moving target on the CRT is pursued by handling a paddle and the automatically measured distance between the target and the tracer is used as a fatigue index. During the test, the examinee will follow the target by his manual movement while analyzing data from the visual system. An input from the paddle is represented on the screen as a point and the distance between this point and the target is measured. In the VRT control and analysis are done by a computer (Fig. 4). Furthermore, since the VRT is mostly composed of software, a great variety of tests are possible for examining activities of the nervous system of high order. The target is made movable in the VRT. The emphasis in the VRT is placed on accurate action based on attention and judgment. We may consider that the VRT very sensitively reflects changes in higher nervous activities. By making use of the VRT we may be able to measure the fatigue resulting from the modern kinds of work in which the sensory nervous system plays a predominant role and this, in turn, will enable us to contribute to alleviating various symptoms due to excessive fatigue. We think that the VRT is useful in measuring fatigue in the visual system, the higher nervous system and some parts of the muscular system such as shoulders, arms and hands. If this apparatus were to be brought to a greater degree of perfection, it would become possible to determine adequate labor standards which will contribute to alleviating such kinds of fatigue as would arise from new types of work which are heavily dependent on the nervous system and thus to prevent occupational diseases related to job stress. In the present study, we intend to report on how the VRT apparatus is made, to examine how effective the VRT is as a fatigue measuring test, and to describe how the VRT test was applied to various kinds of work. First of all, the physical make-up of the apparatus will be described. Next, explanations will be given on programs for operating this apparatus and on how to use them. With these explanations, you are able to operate the machine, but before proceeding to operate it, we must verify if the VRT as a fatigue test can satisfy the following requirements (A.V. Kak, 1981)8): (1) It should have conceptual and empirical validity. (2) It should be free from artifacts. (3) It should be reliable. (4) It should be amenable to standardization. (5) It should have representativeness. (6) It should have minimum invasiveness. (7) It should be practicable and economically reasonable. (8) It should be unaffected by learning effects.

In using this apparatus, the examinee is instructed to follow and pinpoint a target dotted on the screen with a cross-shaped sight connected to a paddle. The computer calculates the distance between the dot and the cross-shaped sight every 0.2 seconds until 300 data are obtained every minute. This process is repeated 3 times. The average values thus obtained are called VRT-M and the standard deviations are called VRT-D. By examining the learning effects, daily and weekly variations measured by this apparatus, it became clear:

(1) that when analyzed by means of variance analysis and the learning ratio, learning effects were observed in VRT-D but learning curves suggest that in VRT-M and VRT-D learning effects disappear after the examinee practises in about 5 trial tests.
(2) that examination of weekly variations showed no significant variations in VRT-M and VRT-D except slightly higher values on Monday than on the other days of the week.
(3) that in diurnal variations, VRT-M and VRT-D did not show any significant changes as CFF values.
(4) that from the viewpoint of similarity, VRT-M and VRT-D showed no significant correlations with near point distance, but significant correlations were observed among CFF values.

Fig. 5. Portable Fatigue Meter
A small LED is at the top. A push button is at the centre. The three numbers at the bottom show the frequency of the LED indicator.

2) The Portable Fatigue Meter

Eye strain and the fatigue of neck and arm muscles produced by the use of computers have become a significant occupational health problem in a wide range of occupations. Factory work is changing from physical or skilled labor to the maintenance and monitoring of automated machines. In offices, computer operation is increasingly replacing writing. Fatigue can be assessed with several types of apparatus but such assessment requires expensive instruments and complicated procedures that are not suitable for a work-setting fatigue assessment where a simple, accurate method is needed.

To simplify the assessment of fatigue in the workplace, the authors designed a convenient apparatus called the Portable Fatigue Meter (PFM)[9], which measures critical flicker fusion frequency (CFF). Dimensions of the PFM are 57(W) × 207(D) × I 7(H) mm (Fig. 5). A light-emitting diode (LED) is recessed 5 mm below the surface in an indentation that provides the background against which the LED is viewed, and the button and a frequency indicator liquid crystal (LCD) are placed on the lower half of the PFMS front surface. The PFM circuit is similar to that of the flashing-type flicker in which the oscillation circuit drives the LED. When power is applied, the circuit maintains a constant frequency of 55 Hz until the button on the surface is pushed, at which time the frequency begins to decrease at the rate of 1 Hz/s. When a subject perceives the flashing light, he/she pushes the same button. The frequency at which the subject reports the appearance of the flicker is indicated below the button.

The Portable Fatigue Meter assesses central nervous fatigue by measuring the frequency at which the flicker of a light can be detected visually, called the critical flicker fusion frequency (CFF). But such an apparatus is usually large and expensive. Because the small, light and inexpensive PFM can be carried in a worker's pocket, fatigue can be assessed easily during work, and workload can be adjusted to improve health and productivity. The circuit is simple and uses a common integrated circuit that does not require calibration. The PFM is now mass produced and marketed under the name Fatigue Meter (Tsukare Meter in Japanese) and it has the potential to become a common method of assessing fatigue. While CFF has been used for many years, measurement is sensitive to the degree of fatigue. The effect of a difference in luminance between the PFM and the standard flicker apparatus has been studied[10] and several applications to field research have been reported[11]. In the former paper, the CFF values measured with the PFM and ordinary flicker apparatus showed significant correlations with each other. The new PFM apparatus has almost the same characteristics as the ordinary CFF apparatus.

3) Indicator of immune system for fatigue

We investigated to elucidate the effects of physical fatigue on immune parameters of peripheral blood and splenic T cells in rats exhausted with a consecutive load of swimming[12]. As a result, the number of white blood cells and peripheral blood lymphocytes decreased significantly just after swimming and returned to the baseline one day after swimming in both the single- and consecutive-load groups. But in the consecutive-load group total white blood cells and lymphocytes decreased once again 7 days after the last swimming. Concentrations of plasma corticosterone had increased significantly just after swimming, and returned to the baseline one day after swimming in both groups. Percentages of peripheral blood CD5+ cells, CD4+ cells and CD8+ cells in the single-load group had increased significantly just after swimming. The percentage of peripheral blood CD5+ cells and CD4+ cells had increased significantly one day after swimming in the consecutive load group. Percentages of splenic CD5+ cells and CD4+ cells had increased significantly in the single-load group. However, only those of CD4+ cells had increased significantly just after swimming in the consecutive-load group. A single load had affected the proportions of CD5+ cells, CD4+ cells and CD8+ cells just after the load but the consecutive load affected CD5+ cells and CD4+ cells and the effect persisted until the next day. These results indicate that the effect of fatigue on immune parameters depends on the level of fatigue, and that measurement of subsets of peripheral blood r cells is useful in evaluating various levels of fatigue.

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