Human fatigue as a phenomenon modulated by environmental and typological factors: an approach based upon a complex test structure

By I. MADARÁSZ and P. HUNYA

Between the numerous psychophysiological testing methods currently used in ergonomical, psychological laboratories for detecting fatigue there seems to be an apparent lack of coherence. This is due to the fact that each testing method has been developed on purely empirical grounds because of the unsatisfactory degree of general validity of the theories concerning fatigue-dynamics. The early concepts about the nature of fatigue are founded on contemporary physiological theories of simple *muscular* tiring. These concepts are characterized by making use of this rather primitive, mechanistic analogy in elucidating a phenomenon much more complicated than simple muscular contraction. One cannot escape the suspicion that the main cause of the survival of such a "per analogiam" theory, in spite of numerous experimental facts indicating its inaccuracy, has to be found in the essentially conservative nature of the so called "common", as well as "scientific" sense. The main subject of this paper is the outlining of a more coherent picture of the different mechanisms (physiological and psychological as well) which presumably take part in the fatigue in general, and later on the outlining of a method of investigation and evaluation which has been used by us in our attempt to measure this phenomenon more objectively.

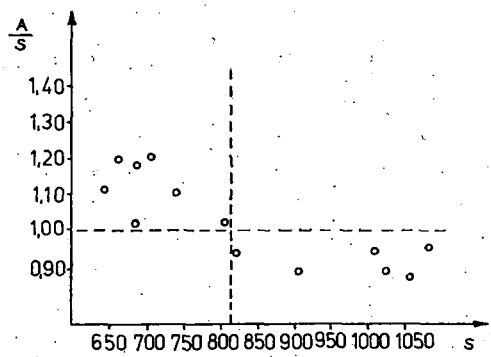

Fig. 1. Changing of control-goodness measured in tremor tests (aiming and static) caused by equal work-load in a group of car drivers. Abscissa: control-goodness at the start of the work-loading; ordinate: arrival start control-goodness ratio.

In our opinion the phenomenon called fatigue is in its essence a psychophysiological *reaction* and therefore cannot be characterized by such purely quantitative parameters as the height of muscular contraction or the number of errors made during a simple test of routine psychological practice; e.g. the crossing out of all vocals in a printed text, etc. In other words: the fatigue, being essentially a special human *behavioral manifestagion* is *not* necessarily equal or even proportional

to any of the output quantities measurable *separatedly* in common laboratory testing procedures.

What is the main consideration in saying that the fatigue cannot be a simple decreasing in a stretching force as that of a spring moving a clockwork? This is due to the fact that man behaves in *real* work-situations like an adaptive automaton, i.e. he changes continuously the *quality* of his adaptive reactions, in other words, the characteristics of the transfer functions of his respective controlling subsystems. The terms both "adaption" and "real work-situation" need to be clarified.

Speaking about the adaptive side of the fatigue as complex behavioral reaction means, that we are bearing in mind the essentially *purposeful* nature of any human working activity. Purposefulness is meant as an objectfunction which has to be optimized. During the performing of a work either of physical, or of intellectual type, *fatigue-causing factors* are acting upon the organism as input quantities, which may take their origin either from the outer, of from the internal environment. Because of the homeostatic nature of the biological systems, *adaptation* tends to eliminate the "disturbing" fatigue-causing inputs, and it is easy to see that this may occur either by *habituation* (decreasing the sensitivity of the input peripheric organs), or by "*active*" *counteraction* against the fatigue-causing inputs, i.e. a) decreasing the rate of work, b) ceasing with working for a while, if it is possible under the circumstances given.

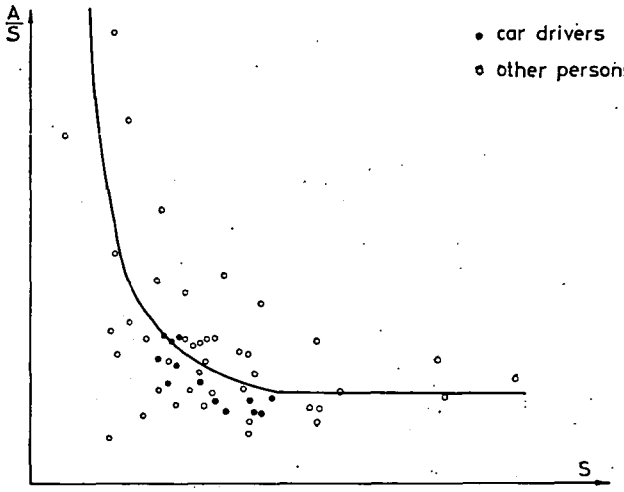

Fig. 2. Changing of control-goodness in tremor tests (aiming and static) in a mixed group.

What *real* work-situation means will be different according to the type of work to be done. In common clerical work, for instance, activity can be suspended for shorter or longer intervals allowing thus the reequilibration of the disturbed balance between fatigue-causing factors and adaptive mechanisms. But if the elimination of all the fatigue-causing factors should be incomplete during a long period of work, the subjective feeling of tiredness and a net *loss in general adaptation capacity* will result. This statement is supported — as to the adaptation capacity loss — by physiological experiments on laboratory animals conducted by us, where some neuro-hormonal adaptative mechanisms were found decreased after a difficult-task and highly motivated learning session.

The degree of difficulty of a car driver's work will again depend in many aspects on the nature of the task to be fulfilled, but it remains more of psychological than that of muscular character. The car driver can most properly be considered as a human operator in a man-machine system. The practical consequences of this view are rather far-reaching if we consider that the quality of performance of a given

man-machine system depends in most cases on the *controlling* characteristics of the human operator's control system. Turning again to the point of the so called real work situation it can be established that the peculiarity of a car driver's work is in the fact that *he has to keep on controlling* his vehicle independently of the actual state of his energy-balance; he has continuously to mobilize spare energies from *other control systems* in order to fulfill the obligatory task, i.e. the keeping of the vehicle on road according to the rules of the correct driving behavior.

The experimental work, the first results of which we are going to report, has been based on a hypothesis according to that at the present level of technological civilization fatigue can be expressed, first of all, not by the decreasing of physical output of the work done, but much better by that of its qualitative indexes. In other words it means that *fatigue is expressed in the restriction of adaptation capacity* to the external and internal conditions, in the deterioration of the complex control function as a whole, which results in the decrease of work-efficiency after consuming the reorganization reserves at disposal.

It is supposed that the elements of the complex control system realizing human adaptation are subsystems whose output quantities can be measured as concrete physiological manifestations. In the case of experimental investigation of numerous and selected subsystems it is expected that we can get a measure about the goodness (correctness) of the control activity of the complex system too.

To find a minimally acceptable compromise with the requirements of theoretical considerations, methodological possibilities, as well as mathematical formulization — often contradicting to one another — we have chosen for experiments a set of subsystems, on the basis of our preliminary investigations. We supposed, that each of them represents a more or less independent control activity of physiological nature. They are the following:

1. The constancy of opto-motor reaction time and its dependence from the interstimulis interval,

2. the so called error-time, (test earlier published by us) which essentially reflects the estimation errors in the time and space coordinates of a moving target,

3. the physiological variant of the intention tremor called by us aiming tremor,

4. the so called static tremor reflecting the physiological postural lability of an arm in resting condition,

5. data of blood pressure measurements.

Each of the physiological mechanisms was the subject of investigation in a testing procedure, separetedly. The testing procedures were carried out on healthy adult persons.

One of the peculiarities of physiological measurements in humans is that the uncontrollable effects are greater in number than in animal experiments. The equipment for measuring the selected functions has been constructed therefore with the aim to reach the greatest measuring accuracy possible. We have made it suitable to record and store automatically hundreds of data per person. The nucleus of the experimental setup consists of a multichannel analyser of 1024 words (16 bit each) capacity. By means of a few modifications in its original hardware it has been made capable of performing operations in a stored-program mode too, enabling thus the automatic control of the whole running of the tests, including the storage and partial processing of the data received from the experimental subjects, as well as the punching of the results on tape for further processing.

The series of light flashes in the reaction-time behavior test characterized by a structured, pseudo-random distribution of the interstimulus-intervals was produced by the central control unit of the analyser. The appropriate programs realizing this stimulus-structure were written with the purpose of producing a modelled sequence of the different, adaptation-evoking input patterns acting normally upon the driver under real working conditions. It has been the stored-program operating mode that made it possible too, applying differently shaped generative functions for the moving-target test. The adaptive capacity required from the subject was tested by changing the speed, as well as the contours outlined by the moving lightspot on the screen. The functioning of the measuring device used in the detection of the so called aiming and static termor was governed also by a central control unit. The design and operating principle of the apparatus was published earlier.

As results of the tests we have received essentially functions that expressed the deviation of the examined "elementary" control activities from the ideal ones. We have not examined the whole course of these functions; for the moment we have watched only 3 control-theoretical characteristics, namely

1. the mean value of deviation from the ideal control,
2. the mean value of squared deviation,
3. the maximal deviation.

The results of individual tests are expressed by triplet numbers. These numbers define, as coordinates, a point in an Euclideal space. The distance of this point from the origo will be a measure of the goodness of the control in a given test. As the triplet numbers of all the tests are essentially *general distances* in themselves, it is justified to consider all the components of different tests to be the coordinates of a 3. N. dimensional space whose certain three dimensional subspaces characterize a test by each. N equals the number of the tests applied. If necessary, each arbitrarily selected subspace can be drawn together. A single generalized distance will then result measured from the origo, without losing significant information, because we have kept the distances as quantities characteristic for the goodness of control activity.

After choosing the experimental equipment and mathematical system of the evaluation of data, our aim was to investigate the control characteristics received from the tests according to their sensitivity. We tried to determine experimentally those subspaces in which the changes of work-productivity — i.e. the control-goodness deterioration supposed by us — appear in proportion with the degree of fatigue.

Our first observations were done with professional drivers exposed to measurably equal work loads. The theory and praxis of the objective measurement of loading factors in car-driving are explained in detail in the paper of D. Muszka.

With this group our aim was set to find experimentally a *measure* characteristic first of all to the degree of fatigue. As there was no possibility to prove that the individual tests applied represent independent control activities, we chose heuristically subspaces supposedly of great informative value and the generalized distances obtained in them were analysed. It has been found that certain phenomena can well be illustrated in a coordinate system with axes as starting values, respectively quotients of arrival/start. It will be perhaps of interest to note that the subsystem choosen was that of the different tremor phenomena (aiming and static) (Fig. 1).

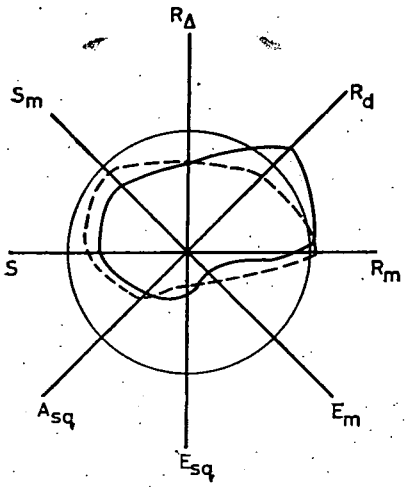

Fig. 3

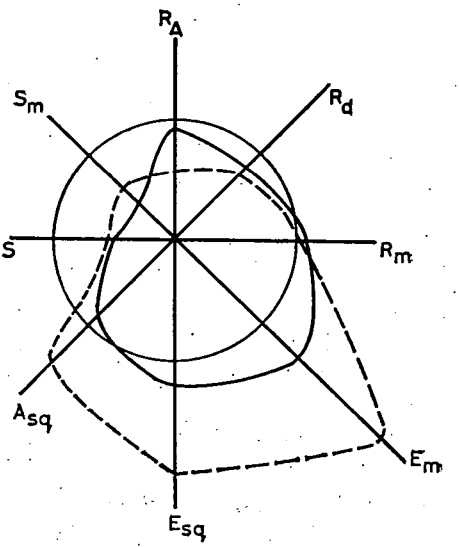

Fig. 4

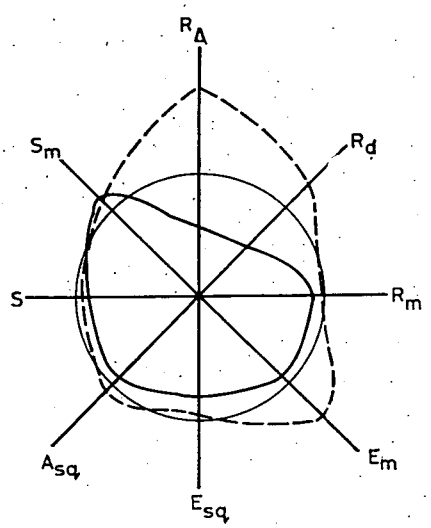

Fig. 5

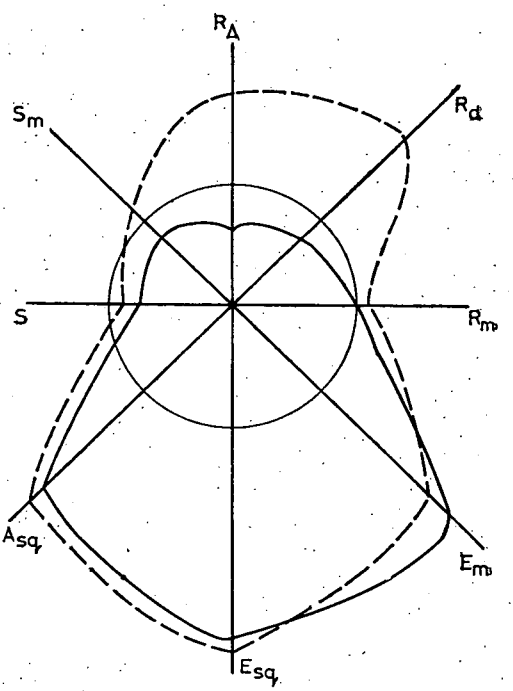

Fig. 6

Two-dimensional illustration of the individual control-efficiency change in the multi-dimensional space. Explanation in text.

It was found that the characteristics of persons starting with good levels of control-capacity (left upper compartment) showed deterioration to the work-load, while others starting with moderate, or even great deviations from the ideal were improving under the same amount of load (right bottom compartment). The conclusion drawn from the data was that the mechanistic theory of the fatigue considering it as a simple decreasing of energy at the output side — is obviously untenable.

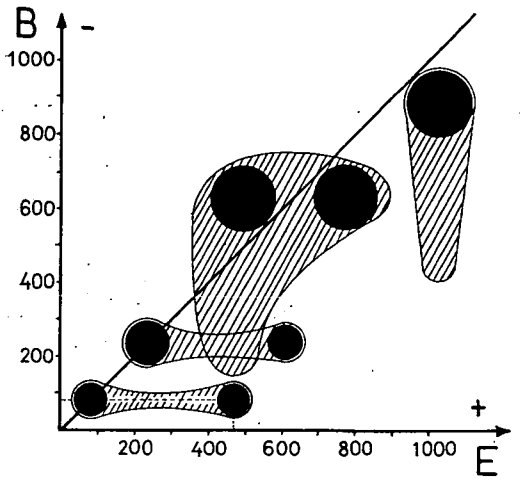

Fig. 7

In the following period a greater and more heterogenous group of persons was investigated in multiphasic testing experiments. The quantitative value of work-load was not measured in this group, but it could be well apperoximated saying that it had the usual measure of their normal workday. Fig. 2 shows the results obtained.

Investigating the same subspace as before, we could state that professional drivers fit well into the whole distribution forming a relatively stable and uniform central part of it.

To examine and illustrate — rather qualitatively than quantitatively some principally important features of the individual control-efficiency change under work-load, the figures 3. 4. 5. 6. can be used. Certain characteristics of each test are mapped as distances along the 8 axes in the figures namely, R_m mean value of reaction time; R_d standard deviation of reaction time; R_A variancy range of reaction time; S_m mean deviation of static tremor; S generalized distance in the static tremor's subspace; A_{sq} mean squared deviation of aiming tremor; E_m mean deviation of error-time; E_{sq} mean squared deviation of error-time.

The solid line represents the initial state, the broken one the state of arrival, while the circle stands for the mean values of the initial state for the whole group.

These specially-shaped, spherical patterns reflect properties of controlling activities in different aspects of a single individual. The following features are to be stressed:

1. The persons as individuals produce particular, similar patterns by repetition.

2. Under the effect of work-load almost every person shows a reaction of particular dynamics as reflected in the independent novement of each element characteristic for his pattern.

3. Numerical measures can be derived, proportional to the area of the spherical pattern, but these give seemingly less information than the pattern as a whole.

From the very beginning our working-hypothesis was that particularities of the dynamics of human fatigue can be understood only on the basis of the cognition of the persons' typological characteristics, i.e. of the cognition of their inherited central nervous mechanisms. That is why we strived to classificate our experimental

persons under work-load into classes. Theoretically it can be done if we try to consider in mind the characteristics of all the tests at the same time. The efficiency of this method, however, is rather doubtful because the data-processing capacity of the human observer's mind is limited and because of the danger of subjectivity. Our investigations aimed therefore at constructing an *automatic classification system* — described in the paper of P. HUNYA — which made it possible to apply automatized classification procedure in this field. The results received as outputs of this classification system are illustrated in Fig. 7.

The perpendicular axe corresponds to the starting overall control-performance, the horizontal one to the value at arrival. The areas bordered by continuous contour-lines mark the limits of groups (classes) pointed by the automatic classification system, their darker nuclei mark the greater frequency of individual cases and their lighter parts the less frequent occurences. We were going to make it clear by this type of illustration that the independent existende of one group (type) is determined, first of all by the position of nuclei, so it may occur that peripherical parts of recognized classes may differ in some extent of overlapping.

Комплексное исследование влияния внешних и внутренних факторов на процесс усталости человека

В работе рассматривается вопрос описания нейрокибернетического механизма процесса усталости. За оценку усталости принимается степень изменения качества функционирования сложных адаптивных механизмов человека, в частности, снижение психомоторных регулирующих действий организма.

На основе сформулированной гипотезы авторы разработали комплексную психофизиологическую испытательную систему.

Полученные экспериментальные данные принимаются за координаты многомерного пространства. Вводятся расстояния, пропорциональные мере усталости испытуемого лица при воздействии эталонной нагрузки.

На основе анализа динамики изменения степени усталости авторами рассматривается возможность классификации исследуемой группы людей (принцип предложен П. Хуня) с использованием самообучающейся автоматической системы.

LABORATORY OF CYBERNETICS
JÓZSEF ATTILA UNIVERSITY
SZEGED, HUNGARY

(Received February 14, 1973)