The Method of Mental Capacity Integrated Assessment for Screening Research, In-Depth Analysis and Improvement of Mental Capacity

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ABSTRACT

This method is developed for practical purposes of the research: assessment of the impacts of environmental conditions, fatigue, emotional effects, pharmacological preparations, etc. It allows to: assess the current state of mental capacity, learning ability; train specialists; carry out professional selection; monitor the mental health of specialist for admission to work, monitor the state in the process of occupational performance; retrace the accumulation of fatigue; identify temporal changes of mental health that are critical for professional activity (human health threatening behavior, emotional stress, family circumstances, interpersonal industrial conflicts, world view problems). This method is based on a modular approach for the automated research, assesses a wide range of mental and psychological functions, it also has three levels of complexity. Its application is illustrated by the results of experimental study of the influence of personal protective equipment under the alternation of physical and information workload.

1.0 INTRODUCTION

Practical use of personal protective equipment for military and emergent conditions needs to be verified in different situations under the impact of numerous factors. Such verification should be adequate and give valid results after experimental investigation. To meet these requirements appropriate methods and tools should be used and/or developed. The most difficult task is to create or to select integrative tool that could give an opportunity to assess human mental physical capacity in different combinations.

The goal of this research is to develop the method of integrated assessment of mental capacity for screening research, in-depth analysis and improvement of mental capacity and to verify it in experimental investigation.

2.0 METHODS

The method is developed for practical purposes of the research: assessment of the impacts of environmental conditions, fatigue, emotional effects, pharmacological preparations, etc.

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This method allows to:

- Assess the current state of mental capacity;
- Assess learning ability;
- Train specialists;
- Carry out professional selection;
- Monitor the mental health of the specialist for admission to work;
- Monitor the state in the process of work performance;
- Retrace the accumulation of fatigue;
- Identify temporal changes of mental health that are critical for professional activity (human health threatening behavior, emotional stress, family circumstances, interpersonal industrial conflicts, world view problems).

This method is based on a modular approach for the automated research. Modularity allows you to change the research volume and its emphasis. Automation reduces labor intensiveness of the research, excludes the human factor in obtaining the data and allows to get formal interpretation of the primary data.

The method assesses a wide range of mental and psychological functions. It allows creating information and sensory workload sufficient to assess the suitability for the majority of certain professions. The basic version of the method has three levels of complexity.

The rate of presentation of test tasks in hour circle does not change. Depending on the objectives of the research it varies from 5 to 10 seconds. The basic cycle of an experiment is 4-6 hours. At the beginning and at the end of basic cycle of the experiment the maximum of possible information processing rate is evaluated. In this case, tests are given with increasing frequency of presentation.

Evaluation of reproductive thinking is carried out taking into account the information capacity of the signal. The boundary capacities of information processing for the test tasks with increasing frequency of presentation are determined in screening research.

Information load was created in the course of the modified Ioseliani test accomplishment in a given rate and other tasks by receiving and processing information in a given rate with the help of automated system for psycho-physiological experiment and complex research, as well as diagnostic equipment [1,2]. They are included in a typical computerized tests "battery": finding of critical flicker fusion frequency (with objective confirmation), teppinh-test, determine the accuracy of reaction to moving object, determination of short-term and long-term memory, volume of operational memory (remembering some of the increasing numbers of memorization), attention (“black and red table”, correcting test with rings and letters), reliability and efficiency of information processing (modified test Ioseliani) [3,4]. The latter was modified by one of authors and realized in the research equipment [5]. Evaluation of mobility of nervous processes was measured by the method of A.E. Hilchenko [6]. Determination of the nervous system strength was based on the determining the fatigue tester at performance in teppinh-test in modification by V.I. Ryzhkov [7].

The duration of this experiment was 6-8 hours without taking into account additional compulsory research and a period of adaptation to experimental conditions. Testing was usually held in the morning by a double-cross method to eliminate possible systematic or random errors.

The formula of aggregate index of occupational performance (APL) determination was proposed to calculate the successfulness of professional performance (SPP) in each particular period of time. This

index is calculated on base of certain professionally important functions of organism (PVF) and permits to make a correct dependencies (that were obtained in the experiment) transfer on the activity of real specialists:

$$A_{ПП} = \frac{1}{n} * \sum_{i=1}^{n} k_i * \left| \frac{(\chi_i - \chi_{\min})}{(\chi_{\max} - \chi_{\min})} \right|, \quad (1)$$

where n – number of valuable PVF indices; k – weighted factors for each evaluated PVF; x_i – value of index evaluated for a moment of carrying out of an experiment; x_{min} – minimal value of this index; x_{max} – maximal value of this index.

Aggregate index of profeccional capability $A_{пвя}$ was calculated according to formula 2.2:

$$A_{пвя} = (A_c + (V_i + V_{min})/(V_{max} - V_{min}) + (m_i - m_{min})/(m_{max} - m_{min}) + (P_7 - 50)/50 + (P_{4.5} - 50)/50)5 \quad (2)$$

where A_c – aggregated index of sensorimotor coordination, relative units; V_i, V_{min}, V_{max} – attention efficiency; accordingly current, minimal and maximal on the test, absolute units; m_i, m_{min}, m_{max} – working memory, absolute units; $P_7, P_{4.5}$ – repiability of reproductive thinking under optimamal and extreme rate of information stream.

Aggregative index of sensorimotor coordination was calculated in the same manner:

$$A_c = ((t_n - 180) / 180 + (t_c - 240) / 240 + (t_m - 0.07) / 0.05 + (D_m^2 - 2*10^{-40}) / 4*10^{-2} + (30 - O_i) / 30) / 5, \quad (3)$$

where t_n – simple sensorimotor reaction time on visual task, ms; t_c – complex sensorimotor reaction time on visual task, ms; t_m – time of elementary movement while tepping-test performing, s; D_m^2 – dispersion of time of elementary movements while tepping-test performing, s; O_i – average dilatation in “moving target response" test.

Physiological cost of work execution was calculated as aggregated index of functional state ($A_ф$):

$$A_ф = \{(ЧСС_i - 50)/120 + (AT_{c.i} - AT_{c.m})/(AT_{c.max} - AT_{c.m}) + (T - 36.5)/2.0 + (ЧД_i - ЧД_m)/(ЧД_{max} - ЧД_m) + (ХОД_i - ХОД_m)/(ХОД_{max} - ХОД_m) + (PWC_{170i} - PWC_{170m})/(PWC_{170max} - PWC_{170m})\}/6, \text{ c} \quad (4)$$

where $ЧСС_i$ – heart rate, per minute; $AT_{c.i, c.cp, .max}$ – systolic blood pressure, accordingly current, average and maximal values; T – body temperature, °C; $ЧД_{i, ср, max}$ – breathing rate, current, average and maximal values, cicle per minute; $ХОД_{i, ср, max}$ - minute breathing capacity, current, average and maximal values, l; $PWC_{170i, ср, max}$ – maximal aerobic capacity, current, average and maximal values, W; n - number of significant figures PVF; k - weights of each PVF, determined; xi - condition index, which is determined during the study; xmin - minimum value of this index; xmax - maximum value of the index.

Confidence index of professional performance Apvya was calculated as:

$$Apvya = (Al + (Vi + Vmin) / (Vmax - Vmin) + (mi - mmin) / (mmax - mmin) + (P7 - 50) / 50 + (P4.5 - 50) / 50) 5, \quad (5)$$

where Ace - aggregated indicator of sensomotor coordination, acting; Vi, Vmin, Vmax - account efficiency and, consequently, the current, minimum and maximum for the test, AU; mi, mmin, mmax - amount of RAM, AU; P7, P4.5 - reliability of reproductive thinking at optimum speed and extreme presentation of information.

Assessment of occupational performance for the entire period of work is made by the generalized performance index (**П**), which takes into account quantitative and qualitative changes of parameters in professional activities and their contribution to final result

$$\Pi_{\text{I}} = \int_{\tau_o}^{\tau_\phi} f(A_{\text{ППП}}) * d\tau, \tag{6}$$

where $\mathbf{П_i}$ – integrated work within the research; $\mathbf{t_0, t_ф}$ – the actual beginning and end of the work time; **f** – $\mathbf{A_{ппп}}$ dependence function and the generalized performance index; $\mathbf{A_{ппп}}$ – aggregated index of a professional.

The effectiveness of a professional military expert activity was estimated as the ratio of obtained generalized index of work capacity to the required values:

$$\text{E} = \int_{\tau_o}^{\tau_\phi} f(\text{A}^{\Phi}_{\text{ППП}}) * d\tau \Big/ \int_{\tau_o}^{\tau_{\text{Н}}} f(A^{\text{Н}}_{\text{ППП}}) * d\tau \text{, where} \tag{7}$$

$\text{A}^{\Phi}_{\text{ППП}}$ – actual aggregated index of professional occupational performance; $\text{A}^{\text{Н}}_{\text{ППП}}$ – needed aggregated index of professional occupational performance; $\mathbf{t_0, t_ф, t_н}$ – initiation time, actual completion time and necessary working time in the process of experiment.

However, not a specific indicator of functional status that would allow unambiguously compare the functional state of the body at different stages of the work or the application of various remedies. It is connected with a specific feature of the influence of equipment and personal protective equipment standard on functional status, and features personal reactions to specific workload.

To evaluate the functional state of personnel use the most informative indicators of functional body systems that are crucial to these terms of: cardiovascular (heart rate) and of thermoregulatory (core body temperature and sweat loss). For general evaluation of functional status appropriate to use integrated indices. They were based on the indicators that transformed in the same range of changes. The calculation was made using the principle of unification of the range which offered Craig [1] to calculate the index of physiological effect (I):

$$\text{I} = \frac{\text{A}_3 - \text{A}_1}{\text{A}_2 - \text{A}_1} \times 100 \text{ , this} \tag{8}$$

$$\text{I} = \text{I}_\text{A} + \text{I}_\text{B} + \ldots + \text{I}_\text{Z}$$

A_1 – value parameter of functional status for comfortable conditions;
A_2 – maximum value for this parameter;
A_3 – value parameter in experiment.
I_A, I_B, ..., I_Z – a list parameters of functional state, which investigated.

[1] Craig RP (1984) Military cold injury during the war in the Falkland Islands 1982: an evaluation of possible risk factors. J Roy Arm Med Corps 136: 89–96.

Koschyeyev V.S. et al [2] to assess the functional tension at work propose a modification index Craig (U):

$$\cup = \sum K_i \frac{\Delta P}{P_o} \quad , \tag{9}$$

ΔP – changes of functional state in the experiment comparing with its optimal value;
P_o – optimal value of this parameter;
K_i – contribution ratio of each parameter in the tension of functional state.

We made analysis of theoretical approaches that are applied in developing these indices. These indices were used to analyze the data of our own experiments. All this is allowed to make a definite conclusion about their value and make three new indices.

Index of functional tension Craig we have modified and defined as the average change of indicators used for its calculation:

$$\mathbf{IFTO} = \left(\frac{\mathbf{P-70}}{\mathbf{100}} + \frac{\mathbf{T-36,5}}{\mathbf{2}} + \frac{\mathbf{M}}{\mathbf{2}}\right) \div \mathbf{3}, \tag{10}$$

IFTO – index of the functional tension organism systems (index FTO).
P – pulse rate at the time of measurement, beats / min;
T – rectal temperature at the time of measurement, °C;
M – sweat loss at the time of measurement, kg/hr;

Assumed that the application of the index makes a definite conclusion about the critical state of functional mechanisms in a given time (estimate at one point). To evaluate the alterations of the functional state over a period of activity, especially if changes of functional state were nonlinear nature, the definition of this index is inadequate. Index FTO ignores time factor, i.e. it does not account for the duration of functional deviations from the norm, and it is imperative to assess fatigue, functional reserves of the body, heat exhaustion. To assess changes in functional status over time the index FTO was integrated over time and get the index FTO -I:

$$\mathbf{IFTO-I} = \int_{\tau 0}^{\tau 1} \left(\left(\frac{\mathbf{P-70}}{\mathbf{100}} + \frac{\mathbf{T-36,5}}{\mathbf{2}} + \frac{\mathbf{M}}{\mathbf{2}}\right) \div \mathbf{3}\right) d\tau, \text{ this} \tag{11}$$

τ_1 – time workload, hour.

To evaluate the equipment was proposed biometric index (I_{BIO}), which allows estimating the speed of change functional state:

$$\mathbf{I_{BIO}} = \left(\left(\frac{\mathbf{P-70}}{\tau_1 * \mathbf{100}}\right) * \mathbf{60} + \left(\frac{\mathbf{T-36,5}}{\tau_1 * \mathbf{2}}\right) * \mathbf{60} + \left(\frac{\mathbf{M}}{\tau_1 * \mathbf{2}}\right) * \mathbf{60}\right) \div \mathbf{3}, \tag{12}$$

τ_1 – time workload, hour.

[2] Koshcheev V.S. & Kuznets E.I. (1986). Physiology and hygiene of individual human safety in condition of high tempereture. Moscoe: Medicine. 256 pp.

3.0 RESULTS AND DISCUSSION

The research of specialists' professional occupational performance under exercise stress is carried out mainly by the standard pattern of physiological and hygienic PPE tests and consisted of three blocks. The first and third block of the research were identical and were properly conducted before and after the main workload.

Before the main workload there were defined: health, psychological status, functional state and condition of the main PVF testers. Vocational important functions were investigated using progressive loading techniques based on an automated computer system of the experiment. The duration of study was 30 minutes. 30 tasks were presented on the screen in each block. Tasks are generated with the help of sensors of random numbers. There are 3 groups of tasks in block that are veried by complexity. The minimum complexity of the task is 23 +34 type (no crossing over a dozen), the average complexity of the task is 37 +47 type or 62 + 53 (there is a shift over a dozen), third level 75 + 68 (two dozen crossings). The signals in a block are randomized on complexity and filtered for the following tasks that are easily remembered and do not require oral calculation (e.g. 50 +50). There are 10 of such blocks. The frequency of presentation of one task in the first block is every 8 seconds. The frequency of presentation of one task in the last block is every 3.5 seconds.

For specialized, experienced and well-trained professionals with certain attention focusing requirements, inverse tasks are applied: negative without background and + (plus selected for background) are carried out as negative, + and - (minus on a dedicated background) are carried out as plus. Errors are properly analyzed as errors of mental arithmetic and attention arrors, if for example the + inverse was used as a + rather than negative.

Examples of signal processing before and after a physical load, according to the frequency of task presenting without inversions and complexity differentiation in the process of analysis are demonstrated in tables.

Cutoff frequency of signal processing is determined by calculation of the exponent and frequency where reliability is 50% (only 50% of tasks are solved correctly). The analysis of frequency of errors by Furye analysis, and reports after the testing additionally allows to determine the strategy of work or the attention focusing frequency parameters.

Table 1: Maximal working time and changes of main professionally important qualities under physical load (mainly) in complex of personal protection facilities PPF (thermo neutral microclimate), M±σ.

Indices evaluated	Control group		PPF use	
	Start	finish	Start	finish
Reliability, %	94,6±2,1	84,1±4,4	93,7±3,9	81,2±3,9
Information processing efficiency, %	87,9±4,1	83,7±4,6	83,7±2,4	51,8±2,7
Critical periodicity of signals, s	3,5±0,2	4,0±0,3	3,5±0,2	4,4±0,4
Working memory	12,2±1,5	11,4±2,3	12,3±2,1	7,8±2,3
Attention	356±12	303±11	342±8	239±180
SMRK index	0,97±0,02	0,78±0,07	0,93±0,03	0,36±0,11
Capability aggregated	0,97±0,03	0,85±0,03	0,94±0,02	0,79±0,02
Maximal rime of work, min	>360		40±5	
Integral capability	5,48±0,13		0,79±0,09	
Efficiency of work, %	91,3±3,6		13,2±0,8	

It was found that during the first working hour the work capacity of military experts who used PPE complex is lower than within the control from 1,2% ($p > 0,05$) to 5,3% ($p < 0,05$) depending on the specific physiological and hygienic characteristics of the remedies that were used. Implementation within six hours of acceptance and processing of information from the load factor 60% of the total amount of time and average flow of information about 14 bit/s led to a further reduction of most indices that were studied. Thus, the average level of reliability when working together in the PPE complex at six o'clock was 85.2%.

Reliability of reproductive thinking has changed as the other indicators of professional performance, which caused a decrease of aggregate indicator of work capacity and performance in general.

Functional state of subjects was determined before and after the experiment. Criterion of functional state were continuously registered by monitor complex DKS4T-01. Obtained resaerch data are presented in Table 2.

Table 2: Functional state of military staff when working in PPF (thermo neutral microclimate), M ±σ.

Indices evaluated	Control group		PPF use	
	Start	finish	Start	finish
Heart rate, per minute	68±4	119±4	68±3	170±1
Blood pressure systolic	118±6	114±4	116±7	116±7
Blood pressure diastolic	73±5	67±7	74±3	63±3
Breath-holding time, inspiration, s	56,7±4,8	41,3±4,4	58,1±5,3	40,1±3,1
Lungs vital capacity, l	4,5±0,2	4,3±0,2	4,6±0,2	4,0±0,3
Skin temperature, average,°C	33,3±0,2	33,3±0,2	33,3±0,4	37,5±0,2
Body temperature, average, °C	35,9±0,2	36,7±0,1	35,9±0,2	38,4±0,2
Warm accumulation, Kkal/kg	0,65±0,23		2,04±0,14	
Sweat lost, kg/h	0,67±0,12		1,31±0,11	
Swet transpiration efficiency, %	82±2		12±2	
Power imputs, W	370±23		395±27	
NFSO-I index	1,54		0,38	
Biometrical index	0,06		1,30	

Notes: NFSO index – index of tension of organism functional systems
NFSO-I index – integral index of tension of organism functional systems

Analysis of these data on the organism functional state while dealing with information workload in termo neutral climate demonstrates that additional workload on the worker's organism is caused by the use of personal protective equipment and is negligible. Implementation within six hours of acceptance and processing of information from the load factor 60% of the total amount of time and average information flow about 14 bps has not resulted in a significant reduction of most studied indicators. Thus, the heart rate according to Styudent's t-criterion significantly increased for complex individual securities only to 9,7% compared with the control of a marginal increase of this index, taken into research up to 150%.

The indicators characterizing thermal state of the organism and system heat had unidirectional minor changes according to t-Student criterion. These changes allow to argue about tension in the irreversibility of thermoregulatory homeostatic indices of body heat. The maximal increase in core body temperature, temperature of the skin, average body temperature did not exceed 0,6 ° C or 20% of the accepted range for research indices.

Thus homeostatic indices did not go beyond the optimal thermal condition of the body for conditions termo neutral microclimate. Regulatory performance varied to a greater range. These changes are largely dependent on the thermal characteristics of individual. Real daily dynamics of micro-climatic conditions,

the results of research and changes in biometric index that don't exceed 0.03/h for PPF and most specifically reflect the compliance of applicable remedies to working conditions, would indicate that remedies do not limit the maximum working time in terms of the functional state of the organism in termo neutral microclimate.

Changes in some indices of functional state of the body reflect the influence of three factors that have a mutual effect on the body. Firstly, this is monotony, stress caused by hours of information loading, secondly - some regulatory mechanisms pressure, caused by the adverse effects of using the personal protective equipment, thirdly - regulatory mechanisms tension to compensate for the difficult body heat with the environment. In a termo neutral climate conditions their joint action appears more pronounced in comparison with control, changes in professional work capacity during the research.

Used toolkit has also helped to detect the deterioration of a number of indicators that describe the status and stability of regulatory functions. Thus, the application of complex coefficient of variation of a simple PPE sensomotorical reaction increased up to 20,5% respectively relative to control. These were the same changes of time variance in the performance of elementary movements teppinh-test, the accuracy rate of sensomotor response to moving object.

Joint analysis of research results in termo neutral and hot and dry microclimate allowed to ascertain that in these research conditions indicators that reflect the most elementary functions have changed the least of all. The nature of changes in other indicators, such as index distribution of attention, showed a negative influence of some factors: the duration of information load - up to 5%, physiological and hygienic characteristics of PPE - 8.2%, microclimate conditions - 1.6%.

Close correlation connection between thermal state, qualitative and quantitative indicators of professional performance and the deadline time of staying in the set of PPE is disclosed. The presence of significant strain of thermoregulatory and other regulatory mechanisms with no signs of imbalance and changes in homeostatic parameters in the application of remedies under termo neutral hot and dry climate and their correlation with the decrease of the general level of occupational performance in long-term information loading is confirmed for adapted testers.

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