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METHODOLOGY FOR ASSESSING THE EFFECTIVENESS OF MEDICAL AND PSYCHOLOGICAL REHABILITATION OF SERVICEMEN OF THE ARMED FORCES OF UKRAINE

The article is dedicated to the development of a methodology for evaluating the effectiveness of medical and psychological rehabilitation of servicemen of the Armed Forces of Ukraine under the conditions of modern combat operations. A comprehensive approach is proposed, which takes into account temporal, resource, and economic factors, as well as psychological aspects. The methodology is based on vector algebra and the Laplace transform for calculating an integral indicator of effectiveness. A numerical example is provided to confirm the viability of the approach. The results may be used to optimize rehabilitation processes and to implement them within the medical support system of the Armed Forces of Ukraine.

Keywords: *medical and psychological rehabilitation; effectiveness; servicemen; vector algebra; Laplace transform; methodology.*

Statement of the problem. The experience of countering the armed aggression of the russian federation convincingly demonstrates that the issue of medical support for the servicemen of the Armed Forces (AF) of Ukraine has become one of the most pressing. However, the discussion must extend beyond timely medical assistance for wounded and injured servicemen to include the restoration of their physical and psychological health following injuries, concussions, and psychological trauma. An effective system of medical and psychological rehabilitation – including preventive measures – for servicemen is a critically important factor in maintaining the combat capability of the AF of Ukraine and ensuring their readiness to perform combat missions. However, the existing methodologies for assessing the effectiveness of medical and psychological rehabilitation systems are limited in that they insufficiently account for the comprehensive nature of rehabilitation, particularly under conditions of martial law.

The modern combat operations associated with repelling the armed aggression of the russian federation have resulted in significant losses among the servicemen of the AF of Ukraine. This makes the issue of effective medical and psychological rehabilitation extremely urgent. Restoring combat capability after injuries, concussions, psychological trauma, and other impairments is a critically important aspect of medical support. Nonetheless, the current methodologies for assessing the effectiveness of rehabilitation efforts have limited applicability in the conditions of martial law, as they do not incorporate a comprehensive approach that considers temporal, resource-based, economic factors, and the specific nature of psychological rehabilitation. This creates the necessity for the development of new methodological approaches that ensure an objective evaluation of the effectiveness of medical and psychological rehabilitation of servicemen in combat conditions.

Analysis of recent research and publications. The issue of medical and psychological rehabilitation of servicemen in the context of modern combat operations is a subject of active scientific discussion both in Ukraine and abroad. Recent studies show significant interest in the problem of restoring the physical and mental health of servicemen who have sustained injuries, concussions, or psychological trauma while performing combat missions. However, most of the existing approaches to assessing the effectiveness of rehabilitation measures are limited by their insufficient consideration of the complex nature of medical and psychological rehabilitation—particularly under conditions of martial law.

In the works of foreign authors, the primary focus is on the use of economic indicators to assess the effectiveness of medical support [1–3]. For instance, in the study by J. Smith et al. [1], a cost-benefit analysis method is proposed, which allows the effectiveness of medical measures to be determined from the perspective of financial expenditure. However, this approach does not take into account temporal, resource-related, and psychological aspects of rehabilitation, which limits its applicability in the military context.

In studies by P. Green, R. Taylor, and others [4; 5], the issue of evaluating the effectiveness of medical rehabilitation is examined in the context of meeting patients' needs. The researchers propose using subjective indicators, such as the level of patient satisfaction with the quality of services provided. Despite the importance of considering the subjective factor, such methodologies have limited applicability in assessing the effectiveness of rehabilitation in combat conditions, as they do not account for objective parameters, including the duration, labor intensity, and cost of the process.

In the context of psychological rehabilitation of servicemen, significant contributions have been made in the research of V. Ivanov, S. Petrov, and K. Anderson [6–8]. In particular, V. Ivanov's work proposes a method for evaluating the effectiveness of psychological rehabilitation based on sociological surveys [6]. The researchers use survey data to calculate coefficients of medical and social effectiveness. However, this approach has a significant drawback: survey results are not always objective, and the sample may not be sufficiently representative to form generalized conclusions.

In domestic research on this issue, the focus is placed on developing methods for assessing the effectiveness of medical support in the military sphere [9–11]. For example, an approach has been proposed for evaluating the effectiveness of medical logistics, which can be adapted for the analysis of rehabilitation processes [9]. However, this approach is limited, as it considers only one effectiveness criterion, while other factors are treated merely as constraints.

Thus, the analysis of recent studies indicates that existing methods for evaluating the effectiveness of

medical and psychological rehabilitation have certain limitations associated with insufficient consideration of the comprehensive nature of the rehabilitation process, especially under combat conditions. This necessitates the development of new approaches that allow for an objective assessment of the effectiveness of medical and psychological rehabilitation, taking into account all key factors, including the psychological condition of servicemen.

The purpose of the article is to develop a methodology for evaluating the effectiveness of medical and psychological rehabilitation of servicemen of the Armed Forces of Ukraine.

Presentation of the Main Material. Medical and psychological rehabilitation, like most managed technological processes, can be characterized by certain indicators, including:

- the degree of completion of specialized medical and psychological rehabilitation measures (Рмр);
- the duration of the medical and psychological rehabilitation process (tмр);
- the labor intensity of the medical and psychological rehabilitation process (Трмр);
- the cost (primarily financial) of medical and psychological rehabilitation (Смр).

That is, the effectiveness of medical and psychological rehabilitation is a function of the listed indicators:

Емр = F (Рмр, tмр, Трмр, Смр).

In this case, it is assumed that the required effectiveness of medical and psychological rehabilitation is achieved when the degree of completion of specialized rehabilitation measures Рмр reaches its maximum value, while the time, labor intensity, and cost are minimized.

Of the four indicators listed, only the determination of the first presents certain difficulties. The calculation of the second, third, and fourth is relatively straightforward, for which simple and appropriate methods are used. A significantly more complex task is determining the overall effectiveness of medical and psychological rehabilitation—specifically, obtaining its integral evaluation, considering all the listed indicators.

The task is further complicated by the following conditions:

1) The aforementioned indicators have different units of measurement, thus they must be converted into relative units;

2) The first of these indicators (the vector-indicator of the degree of completion of specialized medical rehabilitation measures, *Рмр*) is a stimulator**,** meaning its increase has a positive effect on effectiveness, while the remaining indicators are destimulators**,** whose increase reduces the integral effectiveness of medical and psychological rehabilitation.

The solution to this problem can be found through the application of the mathematical apparatus of vector algebra**.** For this purpose, it is appropriate to represent the process of evaluating medical and psychological rehabilitation as a vector originating from a certain point ***O*** — the starting point of the influence on the current state of medical rehabilitation. The task is thus to determine the magnitude of this vector.

We have 4 vectors:

– $\overrightarrow{OA}$ – the degree of completion of specialized medical and psychological rehabilitation measures $P_{мр}$ ($\overrightarrow{OA}=\vec{a}$);

– $\overrightarrow{OB}$ – the duration of the medical and psychological rehabilitation process $t_{мр}$ ($\overrightarrow{OB}=\vec{b}$);

– $\overrightarrow{OC}$ – the labor intensity of the medical and psychological rehabilitation process $Tp_{мр}$ ($\overrightarrow{OC}=\vec{c}$);

– $\overrightarrow{OD}$ – the cost (primarily financial) of the medical and psychological rehabilitation $C_{мр}$ ($\overrightarrow{OD}=\vec{d}$).

Thus, the problem is reduced to calculating the resultant vector $E_{мр}$ (see Figure. 1).

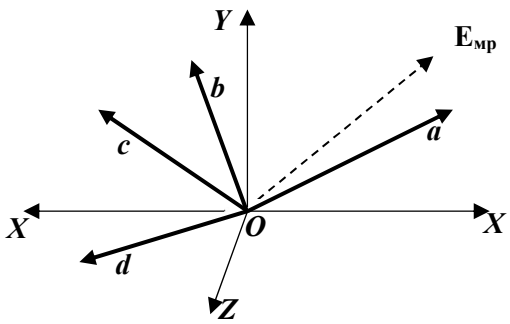

Figure 1. Indicator vectors of medical and psychological rehabilitation (example) Source: developed by the authors

In the general case, the angles between the vectors $\vec{a}$, $\vec{b}$

, $\vec{c}$, $\vec{d}$ may range from 0° to 180°. Moreover, based on the nature of the vectors $\vec{b}$, $\vec{c}$, $\vec{d}$, these vectors should be considered with a sign "–", i.e., the angle between vector $\vec{a}$ and vectors $\vec{b}$, $\vec{c}$, $\vec{d}$ is greater than 90°; the angles between vector $\vec{b}$ and vector $\vec{c}$, between $\vec{b}$ and $\vec{d}$, and between $\vec{c}$ and $\vec{d}$ are less than 90°, but it is not a necessary condition that the vectors $\vec{b}$, $\vec{c}$, $\vec{d}$ are collinear—this means the angles between these vectors equal 0° (collinearity in this case is a particular case).

Given the above initial conditions, the first step in determining the magnitude of the resultant vector is the calculation of the vectors $\vec{b}$, $\vec{c}$, $\vec{d}$. According to the vector addition law, the associative property holds: $(\vec{b}+\vec{c})+\vec{d} = \vec{b}+(\vec{c}+\vec{d})$. In this way, the sum of vectors $\vec{b}+\vec{c}$ is first obtained, and then vector $\vec{d}$ is added to the result $\vec{b}+\vec{c}$.

To determine the angle between vectors $\vec{b}$ and $\vec{c}$, between $\vec{c}$ and $\vec{d}$ the scalar (dot) product rule for non-zero vectors can be used [9]. According to this rule, $\vec{b}\cdot\vec{c} = |\vec{b}|\cdot|\vec{c}|\cos(\vec{b},\vec{c})$, that is, $\cos(\vec{b},\vec{c}) = \vec{b}\cdot\vec{c}/|\vec{b}|\cdot|\vec{c}|$. Note that for collinear vectors, $\cos(\vec{b},\vec{c})=1$.

The sum of vector $\vec{a}$ with the sum of vectors $\vec{b}$, $\vec{c}$, $\vec{d}$ is determined analogously. When performing the calculation, it should be taken into account that the sum $(\vec{b}+\vec{c}+\vec{d})$ has a sign "–", i.e., the expression is: $\vec{a}+[-(\vec{b}+\vec{c}+\vec{d})]$. Thus, the final vector of the effectiveness of medical and psychological rehabilitation $E_{мр}$, is obtained by taking into account all criteria (indicators), their mutual angles, and signs.

To determine the increment (change) in the efficiency of medical and psychological rehabilitation—as a scalar rather than a vector quantity—it is advisable to apply the inverse Laplace transform.

$$f(t)=\frac{1}{2\pi i}\lim_{\omega\to\infty}\int e^{st}F(s)ds, \quad (1)$$

where $F(s)=\begin{bmatrix}F_1(s)\\F_2(s)\\\dots\\F_n(s)\end{bmatrix}$,

s – Laplace transform variable;

$F_i(s)$ – transformed function corresponding to the i-th component of the vector.

To solve expression (1), the resulting vector of the effectiveness of medical and psychological rehabilitation should be represented as a vector function of partial derivatives in the Laplace domain:

$$F(s)=\partial s^n/\partial t+\partial s^{n-1}/\partial t+\partial s^{n-2}/\partial t+a. \quad (2)$$

In order to simplify the solution of expression (1), it is advisable to decompose expression (2) and perform the inverse Laplace transform in parts, independently for each component $F_i(s)$:

$F_i(s)=\partial s^n/\partial t$; $F_i(s)=\partial s^{n-1}/\partial t$; $F_i(s)=\partial s^{n-2}/\partial t+a$,

where n is the exponent.

To determine the inverse Laplace transform, it is advisable to use the following formula:

$$L^{-1}\{s^n\} = \delta(m)(t), \quad (3)$$

where $\delta^{(m)}(t)$ – m-th derivative of the Dirac delta function.

An example of calculating the integral vector indicator of the effectiveness of medical and psychological rehabilitation: $\overline{E_{мр}}$.

Initial Data

Let us assume that the numerical values of the increment for each component of the integral indicator of the effectiveness of medical rehabilitation are as follows:

1. $\vec{a}$ = 0.2 (increase in the degree of implementation of specialized measures from point ***O***, units);

2. $\vec{b}$ = 0.5 (increase in the duration of implementation of specialized measures from point ***O***, units);

3. $\vec{c}$ = 0.7 (increase in the labor intensity of implementation of specialized measures from point ***O***, units);

4. $\vec{d}$ = 0.3 (increase in the cost of implementation of specialized measures from point ***O***, units).

The angles between the vectors are as follows:

$\Theta_{ab} = 30°$; $\Theta_{ac} = 45°$; $\Theta_{ad} = 60°$; $\Theta_{bc} = 15°$; $\Theta_{bd} = 75°$; $\Theta_{cd} = 25°$.

Using the formula for calculating the resultant vector $\overline{E_{мр}}$, we obtain the following expressions:

$$\vec{f} = b + c + d + b{\cdot}c\cos(bc) + b{\cdot}d\cos(bd) + cd{\cdot}\cos(cd),$$

$$\overline{E_{мр}} = a + f + a{\cdot}f\cos(af),$$

where $\vec{f}$ is a conditional total vector introduced to simplify the calculations;

cos(bc), cos(bd), cos(cd), cos(af) – are the cosines of the angles between the corresponding vectors.

It is assumed that the angle between vectors $\vec{a}$ and $\vec{f}$ is 135°.

$$\vec{f} = b + c + d + b{\cdot}c\cos(bc) + b{\cdot}d\cos(bd) + cd{\cdot}\cos(cd) =$$
$$= 0{,}5+0{,}7+0{,}3+0{,}5{\cdot}0{,}7{\cdot}\cos15° + 0{,}5{\cdot}0{,}3{\cdot}\cos75° +$$
$$+ 0{,}7{\cdot}0{,}3\cos25° = 2{,}05.$$

$$\overline{E_{мр}} = a + f + a{\cdot}f\cos(af) = 0{,}2 + (-2{,}05) + 0{,}2{\cdot}(-2{,}05)$$
$$\cos135° = |-1{,}645|.$$

The calculations conducted demonstrate that an increase of 20 percent in any of the vector indicators *b*, *c*, or *d* leads to a corresponding decrease in $\overline{E_{мр}}$ of approximately the same magnitude, as the processes are nearly linear in nature.

Therefore, it can be concluded that the proposed methodological approach is both operationally valid and consistent with the actual processes, and it does not contradict common sense in the evaluation of the effectiveness of complex, multidirectional processes.

Conclusions and prospects for further research. The article proposes a methodological approach to evaluating the effectiveness of medical rehabilitation within the Armed Forces of Ukraine. This approach is based on the application of vector algebra methods. It enables the formulation of a set of indicators for the formalized description of medical rehabilitation and the determination of an integral value of the selected indicators. The feasibility of using mathematical methods for the integral assessment of the effectiveness of medical rehabilitation under combat conditions is also substantiated. A numerical calculation has been performed, confirming the adequacy and functionality of the proposed approach. The prospects for further research include determining the possibility of applying the proposed methodological approach to the formulation of evaluation criteria for the effectiveness of various hierarchical levels within the medical support system. In addition, in future studies, the proposed approach may be employed to optimize the composition of forces and assets designated for fulfilling medical support tasks.

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