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Measuring cognitive potential based on the performance of tasks of various levels of complexity

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Abstract. *Purpose of work.* The article is devoted to the topic of measuring the cognitive potential of a person on the basis of the obtained experimental data in order to identify its potential capabilities, as well as to monitor their dynamics, for example, to diagnose recovery after an illness. This goal is divided in the study into two tasks, namely, to assess the cognitive potential, it is necessary to develop two algorithms: 1. Assessment of the level of cognitive complexity of tasks. 2. Systems of levels of cognitive potential for an individual. *Methods.* The basis of the methods is a set of experimental, including specially developed author's, techniques, as well as mathematical methods for processing data and calculating the entered specific parameters to formalize the cognitive potential. *Results.* On the basis of these methods, methods (and specific formulas) are proposed for calculating the cognitive potential of an individual using experimental data and tasks of various levels of complexity. *Conclusion.* Within the framework of this study, a methodology for determining the value of cognitive potential was created on the basis of the theory of information images / representations, as well as a specially developed web-toolkit for objectifying cognitive skills (including the so-called softskills). This value can be useful, both in studies related to changes in cognitive abilities as a result of the influence of various internal and external factors (for example, learning, diseases, injuries, etc.), diagnostic goals (for example, with the aim of determining the speed recovery after a disease that affects cognitive activity, such as a stroke or SARS-CoV-2), and in the formation of requirements for certain work positions that significantly depend on the cognitive abilities of the individual.

Keywords: cognitive potential, information images, representations, cognitive processes, Stroop test, brain, target stimuli.

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Introduction

The need to measure the cognitive potential of individuals is associated with the urgency of solving a number of problems:

1. Objectification of the applicant's conformity assessment for any working / managerial position.
2. Personalization of knowledge and skills transfer strategies.

3. Improving methods of cognitive diagnosis and rehabilitation after stroke or viral infections (for example, covid-19).

At the same time, today there are many different individual tasks and methods that, with certain assumptions, assess the cognitive abilities of the subjects [1–7]. These techniques are often poorly combined with each other. There are many problems with processing the results, as well as with their interpretation.

To determine and stratify the complexity of various cognitive tasks during 2014–2021, numerous experimental studies were conducted aimed at solving similar problems in various conditions. Based on the results obtained, a corresponding database was developed — 35,000 records of sensorimotor activity results for 433 tasks with different target functions for different age and professional groups. Each record includes the decision-making time, the duration of the motor reaction, indicators of errors of the first and second kind [8].

Over the past year, studies have been conducted that have shown a characteristic and statistically reliable dependence of an individual's cognitive abilities on the COVID-19 disease (taking into account its severity and even with an asymptomatic course of the disease), see, for example [9].

Within the framework of this study, examples will be given in which the cognitive functions of the subjects were studied using three tests: a simple sensorimotor reaction test, a 7-word memory test and a modification of the Stroop test. All of them were presented on the COGNITOM Web platform (cogni-nn.ru) [8]. This made it possible to conduct an objective diagnosis with instant feedback and minimize the participation of an intermediary expert.

Digital display of cognitive processes is defined in the space of 15 parameters of speed and accuracy of simple and sensorimotor activity for 3 interactive contexts (tests) of different levels of complexity.

Thus, for a correct assessment of cognitive potential, it is necessary to solve two tasks.

1. To develop an algorithm for assessing the level of cognitive complexity of tasks.
2. To develop an algorithm for assessing the level of cognitive potential for an individual.

The key to solving the tasks may be the theory of information images / representations proposed by us as the basis of the model of cognitive activity of the human brain.

1. Theory of information images/representations

The basis of the proposed theory is the idea of a universal cognitive unit [9] information image, the space in which it exists, its topology and properties. Information images/representations can be defined as representations of objects and events in any feature space [11, 12]. Within the framework of the theory of information images, we represent the human mind as a hierarchical system of interacting images that is under regular external influence.

Images with higher energy (we introduce the concept of energy E to describe the communicative activity of images) are located "higher"and closer to the edge of the space of information images of the individual. Therefore, they interact much more often. Low-activity images with low energy and greater inertia are located closer to the center of space and relatively rarely enter into active interaction with external stimuli [11].

It is possible to distinguish 4 conditional types of information images, without claiming an unambiguous classification.

1. **Dominant** images define the dominant [5] of human behavior, its informational primary portrait, its main set of the most consciously used informational images, conditionally drawing an analogy with a computer — the contents of RAM.

2. **Active** images are also one of the determining factors in the human information system. However, their influence is somewhat less dominant, and they are used consciously somewhat less often.

These two types of information images relate more to the explicit cognitive processes of the individual.

3. **Passive** images are hidden in human activity and are responsible for his virtual behavior — that is, dreams, fantasies, manifestations in a virtual environment (for example, in social networks under fictitious names, in online games, etc., etc.). In this area is the majority of images related to reflex acquired functions, passive skills, etc.,etc .
4. **Deferred.** These images practically do not appear externally in the conscious activity of the individual. They are included only in certain cases or have their effect without their awareness and allocation to the need.

These two types of information images relate to the implicit cognitive activity of an individual.

It is important to note that the main real information activity of a person is determined by the first two types of images, the third is mostly virtual.

The information image cannot be transmitted through communication between individuals in an unchanged form, because each information image is unique, since each individual has a specific individual experience.

A person is not able to convey the image that exists in his head, in his space of information images, to another person directly. To do this, he uses various communication devices formed by him with the help of a social communication superstructure or — communication field. The communication field is an informational community of individual experience and collective unconscious, formed as a result of a person's presence in society. The communicative apparatus is: speech, a visual way of transmitting information, tactile, symbolic, etc., etc. Thus, the communication field encrypts the transmitted image into a code and decrypts the received code into its own image when communicating with another individual.

The transfer of information images is carried out using the following chain:

Image → communicative field → signal-message →
→ disturbance in the communicative field of another individual → perception →
image

The theory of information images allows us to take a different look at the characteristic patterns in the human mind, correctly interpret and explain some of them. For more information, see [11, 12]. The fundamentals of the theory are used to build models for the diagnosis of various human conditions [13, 14]. In the world, such a direction of describing the cognitive activity of an individual is quite popular, publications on modeling the dynamics of representations/images in the human brain are regularly published [15–17].

In this interpretation, the individual's reaction to the information impact will be presented in the form of activation (that is, the movement of the image /images) from a relatively low level to a higher one. From the point of view of the theory of information images, images used unconsciously have much greater inertia. This leads to more time for their use in conscious communication. At the same time, the human brain selects the closest images for interaction. Therefore, with a conscious attempt to stratify conflicting information flows, we see a significant increase in interference for the native language and an increase in the effect of cognitive dissonance.

2. Calculation of the difficulty level of tasks

There are several ways to calculate the level of complexity of tasks from the point of view of assessing the cognitive abilities of an individual. They can be simply divided into two ways:

1) relative rating;
2) absolute rating.

The first relates to the results of experimental studies, namely, the relative assessment of the resource costs (cognitive, time) of a particular individual for solving problems in comparison with the sample averages, as well as the number of errors.

The second type of assessment is based on determining the fundamental characteristics and differences of the proposed tasks in order to identify the level of cognitive costs, as well as the threshold of solutions (that is, whether the tasks represent an impossible complexity for an individual or a group of individuals).

For the first type of assessment, a substantial database of accumulated tests is needed to identify the most complex and less complex tests for various samples of individuals on average. Such a database was actually created by us [8].

However, such a large amount of data is quite difficult to process correctly in a short time. This is a serious task of the Big Data class that requires special attention. Therefore, in this study we will focus more on the absolute assessment of the complexity of the proposed tasks.

The main factor determining such complexity will be the number of information flows that arise when solving a separate problem [13]. This solution can be interpreted as processing the information image proposed by the task for a certain period of time (reaction time), and activating your own image to issue a response.

The simplest variant of exposure is exposure to a single image without the need for its recognition (for example, a task when you need to press a button when any image appears on the screen). In the "Simple sensorimotor activity"test, 70 identical stimuli were presented sequentially (a red circle with a diameter of 5 cm), an interstimulus interval of 1000 ms, an exposure of 100 ms. Task: press the button immediately when the image of the circle appears on the screen. The duration of the test is not more than 2 min.

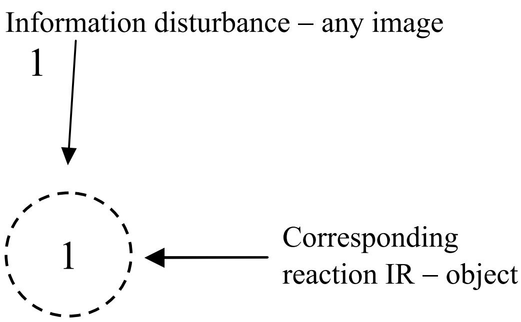


Fig. 1. Простейшая задача

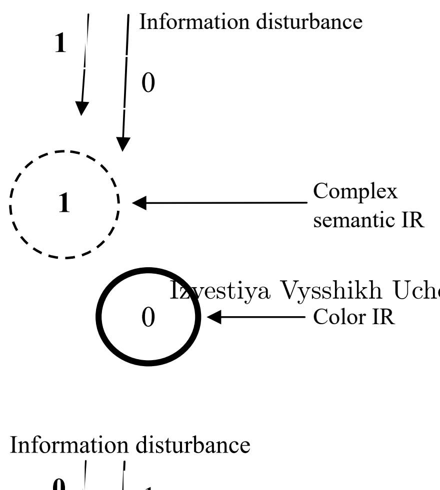
Fig. 1. Simple task

Schematically, this is shown in Fig. 1.

A more complex variant, when there are several or more images, requires cognitive work to recognize and/or compare images.

A classic example of such problems is the Stroop [5] test. In the modified Stroop test (Stroop_mr), the stimuli are color images of words denoting color: red, green, blue, yellow, black. The color of the letters is assigned from the same set of options. The interstimulus interval is 1000 ms, the exposure is 500 ms. Task: press the button as soon as the color of the letters corresponds to the meaning of the word.
In total, 99 incentives were consistently presented, of which 20 were targeted. The duration of the test is not more than 2 min. The total duration of testing was no more than 10 minutes.

From the point of view of the theory of information images, the resulting mismatches in the perception of text and color images are associated with the formation of different flows of information disturbance in the space of information images. Accordingly, the reaction to



this disturbance is given by the closest and most active images.

In Fig. 2 shows schematically the process of processing information flows during the Stroop test. There are two conditional information disturbances (flows) — "text— 1 and "color— 0. They do not coincide, causing cognitive dissonance of the interaction of two information images — semantic and color. There are two options when you need to choose either the meaning of the word — in Fig. 2 on top, or the color on the left — in Fig. 2 from below.

Concentration on one of the information flows without activating the other requires conscious blocking of unconscious reactions to familiar stimuli (for example, color selection by color). The effect of cognitive dissonance is explained here by the mismatch of the activity of information images involved in multidirectional disturbances of the communication field, inconsistent with unconscious adaptive reactions. The need of the mind to build new logical chains bypassing the existing ones and comparing other image codes with the codes of information perturbations of the communication field leads to an information "failure as a result of which the subjects sometimes "hung"over the choice of color, pulling the arrow on the monitor screen from one to another. And only after the elimination of some of the conflicting images in the structure of the decision is the final choice made.

The next level of complexity is represented by tasks with the need to decipher, or determine the desired image with conflicting information flows. For example, when translating from a foreign language, with a low level of proficiency (рис. 3).

Thus, based on this interpretation of cognitive activity, it is possible to stratify the level of complexity of the proposed tasks — depending on the number of information flows and the types of cognitive actions required for their processing.

For example, in Fig. 1 the simplest case is depicted, where there is one information flow, without the need for its processing (interpretation), thus its cognitive complexity $Ss = 1$ (determining the appearance of any flow) $\times$ 1 (choosing the necessary information flow).

Multiplication by the number of threads occurs due to the parallelism of providing information, and not in a sequential way, which significantly complicates decision-making and causes the appearance of the effect of cognitive dissonance.

It is important to note that we are talking about tasks without taking into account the learning effect.

In Fig. 2 we have two streams and the need to interpret one of them, thus: $S_c = (1(\text{matching meaning or color}) + 1\ (\text{determining the appearance of any stream})) \times 2(\text{selection of the necessary information flow}) = 4$.

For fig. 3 a translation is added (that is, the definition of the image in the native language to the image in a foreign language) and $S_c = 6$.

An approximate form of the generalized formula for the cognitive complexity of the task can be represented as follows:

$$S_c = \left(\sum_{i}^{n} 1\right) * I(1), \tag{1}$$

where n — the number of images involved in processing, i — image number, I — the number of information flows that need to be processed.

3. Cognitive potential

Thus, we determine the level of complexity of the tasks in terms of the cognitive costs of solving them. Due to individual characteristics and abilities of a person, one should not directly talk about the correspondence of cognitive potential and the level of problem solving. That is, if an individual with an acceptable number of errors and time costs solves problems at the level of $Sc = 5$, then his cognitive potential is 5. It is possible that for some reason it will be easier for him to solve level 6 tasks (for example, because there will be operations with color images, and at level 5 he was given semantic ones, which is a more difficult task for this particular subject).

Therefore, in such a paradigm, it is necessary to take an integral rating taking into account the solution of problems of different levels and with different types of images at the same level. Since the topic of relative indicators of an individual has already been raised earlier, ideally it is necessary to take into account the average indicators for a large sample of individuals on tasks of different levels and with different types of images. In this logic, cognitive potential can be defined as a threshold value of the complexity of the tasks to be solved. When the threshold is exceeded, the individual makes mistakes.

An important factor for our calculations is that we will use as parameters those indicators that are available to us within the framework of the experimental data base under study. The advantage of the selected indicators is their relative availability, the absence of the need for complex equipment to obtain (except for a computer with a mouse), which gives significant potential for large-scale application and testing.

What parameters can we extract from this database?

1. Decision-making time (the time interval between the appearance of the image on the monitor screen and the moment of pressing the button) on average for the task — T_d / average time for making decisions on the database for this type of tasks — $T_{d\text{mid}}$.
2. The duration of holding the button during motor reaction (MR, milliseconds) — T_p / base average — $T_{p\text{mid}}$.
3. Number of target stimulus misses (ERR1) — P_p / base average — $P_{p\text{mid}}$.
4. Number of double taps (ERR2) — P_d / base average — $P_{d\text{mid}}$.
5. Number of clicks on a non-target stimulus — P_m / base average — $P_{m\text{mid}}$.

Having a set of such data, it is possible to determine the complexity of the tasks used in terms of relative values according to the selected 5 parameters. It will look like this:

$$S_r = \frac{T_d/T_{d\max} + T_p/T_{p\max} + P_p/P_{p\max} + P_d/P_{d\max} + P_m/P_{m\max}}{u}, \tag{2}$$

where u is the number of parameters (we have 5). If there is no parameter (for example, there is no error option in the task), then 0 is simply written instead of the corresponding fraction. In each of the fractions, the parameter of the task under study is divided by the maximum parameter from the database for all tasks. Thus, the relative difficulty value will range from 0 to 1, never reaching 0 and having a theoretical possibility of reaching 1 for a task that is the most difficult by all the selected parameters.

Based on these parameters, we have compiled a formula that determines the cognitive potential of an individual (in terms of data obtained as a result of passing a series of tests and comparing them with the results of a sample from the database):

$$P_c = \sum_{j=1}^{m} \left(\frac{T^j_{d\mathrm{mid}}}{T^j_d} + \frac{T^j_{p\mathrm{mid}}}{T^j_p} + \frac{P^j_{p\mathrm{mid}}}{P^j_p} + \frac{P^j_{d\mathrm{mid}}}{P^j_d} + \frac{P^j_{m\mathrm{mid}}}{P^j_m} \right) S^j_c S^j_r, \quad (3)$$

where j is the task number, m is the number of tasks. Accordingly, the ratio of the average obtained parameter value for a separate task in the database is calculated in fractions, divided by the obtained parameter value of the individual under study.

This is multiplied by the difficulty of the task and summed up for all tasks. The final number is the conditional value of cognitive potential, which takes into account both absolute factors of cognitive complexity and relative ones (obtained from the task database).

Conclusion

Within the framework of this research, a methodology for determining the value of cognitive potential has been created based on the theory of information images/representations, as well as specially developed web tools for objectifying cognitive skills (including the so-called softskills).

This knowledge can be useful in studies related to changes in cognitive abilities as a result of the influence of various internal and external factors (for example, learning, diseases, injuries, etc.), and for diagnostic purposes (for example, to determine the recovery rate after a disease affecting cognitive activity, such as stroke or SARS-CoV-2). This approach can be used in the formation of requirements (including interview processes) for certain work positions, which significantly depend on the cognitive abilities of the individual.

The techniques that are commonly used in such cases often require self-assessment of the condition from people with impaired awareness mechanisms, poorly combined with each other, there are many problems with processing the results, as well as with their interpretation. The proposed method can help in solving such problems.

The next stage in the development of this idea will be an experimental study of the dynamics of the recovery of an individual's cognitive abilities, comparing the indicators introduced in our work with data from other methods of assessing the recovery of cognitive potential. This will allow us to sufficiently test the approach and test its effectiveness in comparison with other methods.

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