Characteristics of the psychophysiological state of a human operator in the information system ”human – display”

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Abstract. The paper describes the structural model of a human operator, who perceives information from the display screen. The method for measuring visual fatigue in terms of the stability of clear vision was investigated and developed. The characteristics of attention were investigated. The programs that automate the measurement of visual fatigue and attention were developed. Different types of memory were considered. A structural model of memory is presented, based on which a method has been developed and experiments have been conducted to study the perception of symbolic information from a display screen by a human operator. The results obtained can be used in the design and operation of information human-machine systems.

1. Introduction
The computerization of professional activity has created favorable conditions for productivity improvement, introducing new technologies for managing information processes, simplifying some forms of human operator work. In connection with the development of computer technology, a big step has been made in the study of human-machine information systems. However, during the existence of these systems, it was not possible to completely switch to automatic operation of the system without operator participation. This is due to many reasons; the main ones are as follows. First, the variety of situations in the interaction of the information system with the outside world, including force majeure circumstances that may arise, for example, in the space industry, aviation, power industry. Second, modern computers have no associative ”thinking”. Third, in a dynamically developing external environment, decision-making systems are practically not only ineffective but can lead to disastrous consequences without the influence and support of a human operator.

Creation of automated (with the participation of the operator) information systems is associated with solving the problem of studying the efficiency of human-computer information interaction. The main work of a human operator when interacting with computer is the perception of information, its processing and decision making. The perception and processing of information is the detection, recognition and classification of images shown on the display screen. The image on the display is different from the observation objects familiar to the eye. It consists of discrete points. It glows and twinkles. Colour computer image does not match the natural colours of the spectrum. Visual fatigue is caused not only by the features of the image on
the screen but also by the eye strain during continuous work with the display screen [1]. In the "human-display" system, the maximum load gets to the visual analyzer, therefore, the actual problem of measuring visual fatigue arises. Such characteristics of the psychophysiological state as attention and memory also influence the work of a human operator.

At present, the problem of evaluating the work of a human operator in automated information system has not been solved. Such important characteristics of the psychophysiological state as visual fatigue, attention and memory of the human operator have not been studied. The solution of this problem is a very relevant objective.

The purpose of the paper is to study the psychophysiological state of a human operator in terms of measuring visual fatigue, attention and memory characteristics when processing information perceived from the display screen.

2. Materials and techniques
In order to explore visual fatigue, attention and memory, it is necessary to build a structural model of the human operator perceiving information from the display screen. In [2], based on the notion of human sensory space, the theory of statistical decisions, the laws of psychophysics, engineering and cognitive psychology, a structural model of the human operator’s work while perceiving information from a display screen was developed. This model is presented in figure 1.

![Figure 1](image_url)

Figure 1. Structural model of the human operator’s work.

The structural model is described using three operators. The first operator performs a linear transformation of the incoming impact in the sensory result of observation. The second operator defines a one-to-one mapping of the sensory space into the decision space with the help of decision functions. With the help of the third operator, the observer implements the selected actions. Thus, the structural model of a human operator can be represented in the form of the following subsystems: 1-cognitive, 2-decisive, 3-executive and 4-block of internal sources of information — attention and memory. The block of internal information reflects the influence of a person’s experience, features of memory and attention processes, motivational and evaluative structures, as well as an emotional state on subsystems of the model. However, this paper does not examine how attention and memory affect the work of a human operator.

Let us consider how we can determine the visual fatigue of a human operator in the system "human-display."
Fatigue is a complex physiological process that begins in the higher divisions of the nervous system and extends further to other systems of the body. In [3], fatigue is considered as a state of the body caused by physical or mental work, in which the performance of a cell, organ or the whole body is temporarily reduced. When solving the problem of measuring visual fatigue, this definition is basic.

It is known that the visual analyzer consists of two parts: light-sensing apparatus and motor apparatus. According to [4], the fatigue of the light-sensing apparatus in the operational context is less important than the fatigue of the motor apparatus, after a very short time it comes to a certain stationary state and does not tire further. The motor apparatus, due to excessive tension or often repeated changes of tension and relaxation, can tire much more. Tension is created when it is necessary to focus on very close objects, distinguish small details, often turn a look from one object to another, etc. There are several subjective symptoms of fatigue of the visual analyzer: the "blurring" of the image, eye pain, etc. However, these signs do not quantify fatigue.

For the first time, the retarding effect of visual fatigue on the reaction time was noted in [5]. On exposure of an eye to a photic stimulus, reflex blinking occurs — an unconditional protective reflex. The time of the signal transmission through the reflex arc can be used for assessing the conditions of the visual analyzer. Fatigue is assessed by the reaction time of the protective blink reflex [6], it increases with the progression of fatigue. Visual fatigue can be identified by the critical flicker fusion frequency (CFFF). If a periodically interrupted stimulus acts on the eye, an unpleasant sensation of flicker occurs. If the breaks are quite frequent, it gives the impression of a steady, unwinking light. The minimum frequency at which flicker fusion occurs is called the critical flicker fusion frequency. It decreases with the progression of fatigue.

A number of researchers [3, 4] believes that a characteristic feature of rapidly progressing fatigue is a decrease in electroexcitability of the eyes, which is characterized by rheobase, chronaxia, and lability. In [7], studies of the considered methods for measuring visual fatigue are presented. These studies showed that with the progression of fatigue, rheobase increased by 15 %, chronaxia increased by 20 %. However, there is a significant variation in the measured values of both rheobase and chronaxia. This suggests that this method is not sufficiently accurate, and the measurement of fatigue by the electroexcitability of the eye is a very laborious task. The results of measurements of CFFF showed that when performing a 1.5-hour intense work (working with a display), the CFFF decreases, on the average, by 7 %, and it decreases by 14 % after 3 hours of intense work. Such an insignificant decrease in CFFF indicates that this method of detecting visual fatigue is not sensitive enough. It should be noted that the reaction time of the blink reflex to the photic stimulus increases by 30 % after 1.5 hours of intense visual work, and it increases by 200 % after 3 hours of work. These are significant changes and they can be used with high accuracy for assessing the fatigue of the visual analyzer. These methods can be applied when special devices and instruments are available [7, 8]. It is not possible to use them to automate the measurement of visual fatigue.

To measure visual fatigue, we can use the method of determining the "clear vision stability" proposed by Ferree and Rand [4].

The essence of the method is as follows: the test subject is asked to fix his/her eyes for some time on some small drawn and hardly distinguishable detail, for example, a break in a straight line or in Landolt ring, etc. Under such conditions, the detail can be seen by the subject quite clearly or it can get blurred in his eyes, or it becomes unclear. The subject must, by means of some special signal, mark all the moments when the detail ceases to be seen by him/her quite clearly and all the moments when it becomes clear again. These signals are mechanically recorded on a smoked tape of a rotating kymograph drum next to a parallel recording of time or marked by a stopwatch and recorded. At the end of the experiment, the total amount of all time intervals during which the detail was clearly visible is calculated. The ratio of the entire
duration of periods of clear vision to the total duration of the whole experiment, or to the entire
duration of unclear vision, is taken as a value of the "clear vision stability."

It is also useful to consider the number of changes of periods of clear and unclear vision: for
many people, an increase in visual fatigue leads mainly to the increase in the number of
changes. The success of the work with the use of this method requires a certain training of the
subjects, adherence to sufficient pauses between the tests and the constancy of the conditions
of adaptation of the eyes.

The authors [9] developed a programme designed to automate experiments to measure visual
fatigue of a human operator according to the method of Ferree and Rand using the "clear vision
stability" value.

The principle of its operation is as follows: during the experiment, the subject is invited
to look at the working window of the monitor screen, which shows a black ring on a white
background (figure 2a), from a short distance.

![Figure 2](image)

**Figure 2.** The working window of the monitor screen.

The experiment itself begins with clicking the "START" button and includes ten presentations
of the test object to the subject — a break in this ring. With each subsequent presentation,
the break automatically appears in a new place during a fixed time interval of two seconds. If
the operator sees the break quite clearly, he/she must give the appropriate signal by clicking
the "SIGNAL" button (figure 2b). Each time the operator clicks it, a special field will display
their number and, therefore, the number of periods of clear vision, starting from zero. When
the number of test object presentations is 10, the experiment is considered complete, and the
number of signals is fixed. A total of eight successive experiments are carried out with each
operator, with the break width increasing each time by one pixel from one to eight, i. e. to
such size of the test object when the subject begins to constantly distinguish it clearly. When
the "reset" button is clicked, all results are reset to zero, the "exit" button immediately ends
the program. In the case of the practical application of the method of Ferree and Rand, it is
recommended to take the ratio of the number of clear vision periods to the total number of
presentations of the test object [4] as a value of "clear vision stability". When processing the
obtained experimental data, the average probability of detecting a test object was computed,
i. e. the value of "clear vision stability" taken on average for all operators for each experiment
before the performance of visual work (table 1) and after it (table 2). Calculations were carried
out using the following formula:

\[ C_k = \frac{1}{n} \sum_{i=1}^{n} C_{ik}, \]

where \( C_{ik} \) is "clear vision stability" value of the \( i \)-th operator in the \( k \)-th experiment, \( n = 15 \) is a number of operators participating in it.

**Table 1.** Mean values for unfatigued operators.

| ring opening width in pixels | "clear vision stability" value |
|-----------------------------|--------------------------------|
|                             | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     |
| \( C_k \)                   | 0.653 | 0.847 | 0.927 | 0.967 | 1.000 | 0.993 | 1.000 | 1.000 |

**Table 2.** Mean values for fatigued operators after visual work.

| ring opening width in pixels | "clear vision stability" value |
|-----------------------------|--------------------------------|
|                             | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     |
| \( C_k \)                   | 0.573 | 0.793 | 0.913 | 0.933 | 0.980 | 0.980 | 0.987 | 0.987 |
| \( C_1 - C_2 \)             | 0.080 | 0.054 | 0.014 | 0.034 | 0.020 | 0.013 | 0.013 | 0.013 |

In these tables, \( C_k \) 1 is a value of \( C_k \) computed for the unfatigued operators, \( C_k \) 2 is for fatigued operators after doing the visual work, and \( C_1 - C_2 \) is their difference characterizing the degree of operator's fatigue.

The study of such important human physiological function as attention is of great interest. Attention is the focus of mental activity on certain objects or phenomena of reality (objects of perception) [10]. Involuntary attention arises without any intention, without a predesignated specific goal and does not require any conation. Voluntary attention arises from a consciously set goal and requires certain conation. Attention is not found in the "pure" form, it is always functionally directed towards something. Attention determines the selectivity, conscious or semi-conscious selection of information incoming through the sense organs. Unlike other cognitive processes (such as perception, memory, thinking, etc.), attention does not have its own special content, it appears as though inside these processes and is inseparable from them.

Experimental study of attention is one of the most important for practice areas of research of psychophysiological characteristics of a human operator. When the attention is described as a complex mental phenomenon, the following of its properties are specified: capacity, concentration, division, stability, distractibility, fluctuation, shifting, selectivity [10]. The capacity of attention is measured by the number of objects that can be clearly perceived at the same time (in a relatively short period of time). For an adult human, it is usually equal to 6–8 objects. Concentration is the degree of focusing the mind on an object (objects) in the presence of interference. Division of attention is expressed in the ability to simultaneously perform several actions or to observe several processes, objects. Stability of attention is the overall direction of
attention in the process of the activity. Its main characteristic is the duration of maintaining the
direction and focus of mental activity without departure from the initial level. The opposite of
stability property is fluctuation. Fluctuation is a repetitive involuntary distraction, inattention
to a given object or activity.

Attention shifting is the intentional moving of attention from one object or activity to another.
Characteristic of attention shifting is the degree of difficulty of its implementation measured by
the rate of the subject’s transition from one activity to another. It has been established that the
rate of attention shifting depends on both the stimulus material and the nature of the subject’s
activities connected with it. The ease or difficulty of attention shifting is also determined by the
individual characteristics of the subject, namely by the properties of his/her nervous system. For
those with ”quick-acting” nervous system (the rapid transition from excitation to inhibition and
vice versa), attention shifting is easier to perform. The personal characteristics of the subjects,
namely: their activity and personal interest, level of motivation, etc. are not less significant.

Attention selectivity is selection of some signals from many others. It is a complex
characteristic: it includes both quantitative and qualitative parameters. The quantitative
parameter of the selectivity of attention is the rate at which the subject selects a stimulus from
among many others. The qualitative parameter is the accuracy, i. e. the degree of compliance
of the results of the selection with the original stimulus material.

Obtaining estimates of the characteristics of voluntary attention is of great interest. A special
test programme was developed to automate experiments to determine the characteristics of
voluntary attention using Schulte-Platonov tables [11]. The stimulus material in this task is
the Schulte-Platonov table, i. e. 7 × 7 size table, in which 25 black numbers (from 1 to 25)
and 24 red numbers (from 1 to 24) are randomly arranged. The task is carried out in three
stages. At the first stage, the operator must find and mark the black numbers in the table in
ascending order (from 1 to 25). At the second stage it is required to find the numbers of red
color in descending order (from 24 to 1). Finally, at the third stage, the operator’s task is to
simultaneously calculate the numbers of both colours: black numbers in ascending order, and
red numbers in descending order.

Figure 3. The operator testing program.

Figure 3 shows the operator testing program for obtaining and studying the characteristics
of voluntary attention.
The experimenter uses the following instructions. For the first stage: "You see a table with randomly arranged black and red numbers. You must find and mark black numbers in ascending order. You need to work as quickly as possible and, if possible, without mistakes". For the second stage: "And now you must find and mark the red numbers in descending order." For the third stage: "Now you must do both tasks at the same time, i.e. find and mark black numbers in ascending order, and red ones in descending order. If you make a mistake, you must continue your work without stopping." Each operator's results of each stage (operation time and number of mistakes) are automatically saved and recorded in a text file. Mistake is an incorrectly chosen number or colour. At the end of the experiment, the number of mistakes is calculated (separately for the first and second stages of the experiment). The time of performing the procedures for finding black and red numbers is determined separately at the third stage of the task and the rate of selection is determined at all stages, separately for black and red numbers. Based on the results obtained, conditional values of attention properties are computed.

The programme, appearance of which is shown in the figure (figure 3) has a simple, user-friendly interface that considers the statistics on the test results. It allowed to automate the research of the attention of a human operator in the "human-display" system.

Human memory is the most important characteristic of the "human-display" system. In psychology, memory is considered as a complex function. Three processes are distinguished in it: memorization (data input into memory), storage (retention) and reproduction. These processes are interrelated. The organization of memorization affects retention, the quality of storage determines the reproduction.

In paper [12], the following types of memory are distinguished. By the information retention time, we can distinguish momentary, short-term, operative and long-term memory.

By its relation to the goal: involuntary and voluntary (arbitrary) memory. By the nature of the memorized material: logical, image (visual, aural, haptic); emotional and motor memory.

**Momentary (iconic) memory** is a direct mapping of the image of information perceived by the sense organs. Its duration is from 0.1 to 0.5 sec.

**Short-term memory** holds a generalized image of the perceived information and its most essential elements for a short period of time (on average about 20 sec.). The capacity of short-term memory is 5–9 units of information and it is determined by the amount of information that a person can accurately retrieve after a single presentation. The most important feature of short-term memory is its selectivity. From the momentary memory, it receives only the information that meets the actual human needs and interests, attracts his/her increased attention.

**Operative memory** stores information for a certain, predetermined period necessary to perform an action or operation. The duration of operative memory is from a few seconds to several days.

**Long-term memory** can store information for almost an unlimited period, while there is (but not always) the possibility of its repeated retrieval. In practice, the functioning of long-term memory is usually associated with thinking and volitional efforts.

Memory has the following main characteristics:
1. amount of stored information,
2. memorization rate.
3. storage time (rate of forgetting),
4. completeness and accuracy of retrieval,
5. readiness for retrieval (recall time).

The memory representation in the form of a structural model is shown in figure 4. In this figure, the following notation is introduced: STM - short-term memory, LTM — long-term memory. Through repetition from LTM, information is held in STM for the required time, then it decays (forgetting), moving to other levels in the LTM, in which it can be stored in a huge amount, but it also decays over time. There is a reason to believe that information in LTM
is encoded in a semantic form. This is confirmed by the neurophysiological theory of human perception and memory [10].

Thus, the memory seems to be represented by several phases. The first phase is very short (information retention time is 250 msec — up to 4 sec), it is a sensory direct memory. It is determined by the type of analyzer of the senses and by the way of presenting information. First, in the direct memory apparently all the perceived information is held for a split second, then it is quickly lost, and after hundreds of milliseconds of nervous activity, about 12–20 elements (units of information) remain and move into the operative memory. At the same time, the selection of information is made according to the criteria determined by the observation task. The capacity of sensory direct memory is measured by the number of stimuli (the size of the material presented) retrieved immediately after one short (fraction of a second) presentation. Short-term memory (STM) is determined by a human ability to store information only for the period (up to several tens of seconds, and sometimes more), which is required to solve the current problem. The capacity of the ST memory is characterized by the quality of the singly retrieved (several seconds) presented stimuli. Many experiments have established the "magic" number of 7 ± 2 items that are held in ST memory [10]. The maximum number of items to be retrieved is an invariant of short-term operative memory.

When a human operator perceives information from the display screen, long-term memory also plays an important role. It provides storage of information for a long time (hours, days, months, years). The capacity of long-term memory in the general case is estimated by the ratio of the number of stimuli that remain in memory after some time (more than 30 minutes) to the number of their repetitions. Therefore, in practical measurements of long-term memory capacity (as well as operative memory capacity), its capacity is estimated by the number of stimuli (or information) retrieved after one repetition after some time (more than 30 minutes).

Storing information in memory is a complex process, during which processing, ordering and classification are carried out. In the process of memorizing and storing information, the brain performs its statistical analysis, which allows to estimate the probability of events, and based on these estimates, predict and forecast possible situations and plan activities.

Based on the structural model (figure 4) and the properties of both STM and LTM, we can build a mathematical model of the processes of perception of information from the display screen by a human operator.

For this purpose, it is necessary to conduct an experiment with a group of operators. The experiment was conducted with a group of trained operators and consisted of three parts. Its technique was as follows: the test subject (the operator) sees the form "Test Settings" on the

![Figure 4. Structural model of memory.](image-url)
The test settings include the following parameters: the adaptation time (1 min demonstration delay), the display time, the field for entering the file name in which the test results will be stored. This form has two buttons "Test" and "Exit". After clicking the "Test" button, a new form appears in front of the operator, with the help of which the main part of the experiment was conducted. The "Test" form consists of the upper part and the lower part and has two buttons: "Start" and "Exit". After clicking the "Start" button, after the adaptation time is over, a sequence of characters appears in the upper part of the form. In the first part of the experiment, this sequence consists of letters of the Latin alphabet, in the second part - Arabic numerals are presented, in the third - of characters (! @ # $ % & * () + = ? < > &). The sequence is presented to the operator on the display screen for the time specified in the test settings, then it disappears from the screen. The operator must enter what he remembered in the lower part of the "Test" form. At the end of testing, a message "Test is over" appears. The operator clicks the "Exit" button, and testing ends. Such a cycle was carried out for each operator with a different display time and for a different sequence length. The display time was chosen to be 1.5 sec, 2 sec and 3 sec. The sequence length was chosen randomly from the possible 4, 5, 6, 7, 8 characters. Such sequence length values were determined after preliminary experiments. The experiment was attended by 15 operators aged 20 – 22 years. After passing one test, the subject rested, because testing time was 20 – 30 minutes, which can lead to fatigue. Operators’ fatigue was measured by the method developed by the authors [6].

3. Results and discussion

Let us consider the results of experiments to determine visual fatigue.

The "clear vision stability" value, as shown by experiments, is a random variable. We hypothesize that this random variable has a normal law of distribution. The criterion for testing this hypothesis was Shapiro-Wilk criterion. This criterion is based on the ratio of the optimal linear unbiased variance estimate to its usual maximum likelihood estimate.

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i, \quad s^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2,
\]

\[
W = \frac{1}{s^2} \left[ n \sum_{i=1}^{n} a_{n-i+1} \cdot (x_{n-i+1} - x_i) \right]^2,
\]

where \(\bar{x}\) is mean, \(s^2\) is squared variance estimate, \(W\) is test statistics.

In [13], it was shown that the Shapiro-Wilk criterion is one of the most effective criteria for testing the normality of the distribution of random variables. During statistical processing of data, it was obtained that the "clear vision stability" value, taken on average for all operators, according to the Shapiro-Wilk criterion, has a normal distribution law at a significance level \(\alpha = 0.01\). In order to prove that the "clear vision stability" value for a fatigued operator is reduced significantly, we use Wilcoxon statistical test for homogeneity [13]. This criterion tests the hypothesis of the homogeneity of the two samples, which are the results of measurements of the "clear vision stability" values of a fatigued and unfatigued operator. After applying Wilcoxon test, it was found that the samples are not homogeneous at a significance level \(\alpha = 0.01\). Thus, the difference between the "clear vision stability" values of a fatigued and unfatigued operator is reliable.

Let us find the mathematical expectation, i.e. the mean value of "clear vision stability". For the unfatigued operator, it is equal to 0.92, and for the fatigued operator, it is 0.89. It is easy to see that in the second case, this value decreased by 3.37 %, which will be just a quantitative characteristic of the visual analyzer fatigue progression.

Let us consider the results of experiments to study the attention of the human operator.
The results of the experiments conducted with a group of fifteen operators are presented in the table 3.

Table 3. The results of the experiments conducted with a group of fifteen operators.

| operator | 1 stage | 2 stage | 3 stage |
|----------|---------|---------|---------|
|          | T1, sec | r1      | T2, sec | r2      | T3, sec | T3 black, sec | r3 black | T3 red, sec | r3 red |
| 1st      | 29      | 1       | 30      | 0       | 70      | 35      | 1         | 35      | 0       |
| 2nd      | 35      | 0       | 33      | 1       | 85      | 43      | 0         | 43      | 1       |
| 3rd      | 43      | 0       | 58      | 0       | 86      | 43      | 0         | 43      | 0       |
| 4th      | 46      | 0       | 41      | 0       | 79      | 40      | 1         | 40      | 0       |
| 5th      | 61      | 0       | 43      | 1       | 89      | 45      | 0         | 45      | 0       |
| 6th      | 50      | 0       | 46      | 0       | 73      | 37      | 1         | 37      | 0       |
| 7th      | 53      | 0       | 47      | 0       | 99      | 50      | 0         | 50      | 0       |
| 8th      | 61      | 0       | 43      | 0       | 104     | 52      | 0         | 52      | 0       |
| 9th      | 62      | 0       | 60      | 0       | 98      | 49      | 0         | 49      | 0       |
| 10th     | 42      | 1       | 40      | 1       | 100     | 50      | 0         | 50      | 0       |
| 11th     | 56      | 0       | 48      | 0       | 101     | 51      | 0         | 51      | 0       |
| 12th     | 46      | 0       | 34      | 0       | 71      | 36      | 1         | 36      | 2       |
| 13th     | 45      | 1       | 51      | 0       | 109     | 55      | 0         | 55      | 0       |
| 14th     | 61      | 0       | 59      | 0       | 119     | 60      | 0         | 60      | 1       |
| 15th     | 44      | 0       | 38      | 1       | 96      | 48      | 1         | 48      | 0       |

Here $T$ is the task performance time for the operator at each stage, $r$ is the number of mistakes made by the operator. In practice, it is often useful to compute the mean values of $T$ and $r$, in order to compare the characteristics of each individual operator with them (table 4).

Table 4. The mean values of $T$ and $r$.

| 1 stage | 2 stage | 3 stage |
|---------|---------|---------|
|         | T1, sec | r1      | T2, sec | r2      | T3, sec | T3 black, sec | r3 black | T3 red, sec | r3 red |
| 49      | 0.2     | 45      | 0.26    | 92      | 46      | 0.33    | 46      | 0.26    |

As it was already mentioned, the selectivity of attention is a complex characteristic, which includes both quantitative (rate) and qualitative (accuracy) parameters. According to [11], the accuracy value of attention selectivity is the task-performance accuracy coefficient ($A$), which is computed by Whipple’s formula:

$$A = \frac{N - r}{N},$$  \hspace{1cm} (1)

where $N$ is the total number of stimuli presented, $r$ is the number of mistakes (incorrectly detected stimuli). (In our case, $A_{\text{mean black}} = 0.9920$, $A_{\text{mean red}} = 0.9892$; at the stage of combined activity: $A_{\text{mean black}} = 0.9868$; $A_{\text{mean red}} = 0.9892$).

The quantitative value of the attention selectivity can be the selection rate ($S$) — the time spent on one stimulus:

$$S = \frac{n}{t},$$  \hspace{1cm} (2)
where \( t \) is the time spent by the test operator to find a special stimulus \( n \). (In our case, the selection rate \( S_{\text{mean black}} = 0.5102 \) sec, \( S_{\text{mean red}} = 0.5333 \) sec; under the condition of combined activity (at the third stage of the experiment): \( S_{\text{mean black}} = 0.5435 \) sec, \( S_{\text{mean red}} = 0.5217 \) sec). Change in the selection rate can also be a conditional value of the attention stability. The conditional attention concentration value (\( K \)) will be the ratio of the task-performance accuracy coefficient (in interference environment) (in this case, the third stage of the experiment, \( A_{\text{int}} \)) to the accuracy of the task performance without interference (in the first or second stage, \( A_{\text{no int}} \)): 

\[
K = \frac{A_{\text{int}}}{A_{\text{no int}}},
\]

where the calculations of the accuracy coefficient, both for interference conditions and for conditions without interference, are made according to the Whipple’s formula. (In our case, \( K_{\text{mean black}} = 0.9948; K_{\text{mean red}} = 1.0000 \)). In this case, the attention division coefficient (\( C \)) is computed as the result of the ratio of the number of numbers correctly recorded by the operator to the total number of stimuli presented \( N \):

\[
C = \frac{N - r}{N}.
\]

Here, the greater the value \( C \), the better the division of attention. In the study of shifting attention, the task of the subject is the combined performance of two or more tasks. Then we compare values of the selection rate in the conditions of combined performance of actions (\( S_{\text{com}} \)) and without it (\( S_{\text{no com}} \)). (In our case, \( Q_{\text{mean black}} = 0.9387, Q_{\text{mean red}} = 0.9782 \)):

\[
Q = \frac{S_{\text{com}}}{S_{\text{no com}}}.\]

The results of this study can be used to optimize the human operator interaction with the display in modern automated and computerized design and process control systems.

The results of experimental studies of work of the human operator in the perception of information from the display screen.

According to the results of the experiment, the probability of correct answers is computed as the event frequency

\[
p = \frac{n_x}{N_x},
\]

where \( x \) is the length of the sequence, \( n_x \) is the number of correct answers, \( N_x \) is the number of presented sequences for each of the test subjects.

The calculated values of probabilities of correct reproduction of sequences were averaged over all operators.

The correct reproduction probabilities (averaged over the operators) \( \mathcal{P}_{\text{correct rep}} \) with different display time are presented in table 5.

Let the length of the sequence \( x \) be a random variable. To obtain the distribution law of this random variable, the probability of correct reproduction is presented in quantiles of normal distribution. The relation \( \mathcal{P}_{\text{correct rep}} = f(x) \) was approximated by a straight line by the least squares method.

Analysis of the results of experiments showed that the probability of correct reproduction of sequences of different lengths for each operator is described by the normal distribution function

\[
F(x) = \frac{1}{\sqrt{2\pi}\sigma_x} \int_0^x \exp\left[-\frac{(x - \bar{\ell})^2}{2\sigma_x^2}\right] dx,
\]
Table 5. Probability of correct reproduction of symbol sequences.

| Display time 1.5 sec | Alphabet Sequence length | Numbers $P_{\text{correct rep.}}$ | Letters $P_{\text{correct rep.}}$ | Characters $P_{\text{correct rep.}}$ |
|---------------------|--------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| 4                   | 1                        | 0.606                             | 0.403                             |
| 5                   | 0.905                    | 0.504                             | 0.208                             |
| 6                   | 0.790                    | 0.333                             | 0.131                             |
| 7                   | 0.533                    | 0.183                             | 0.010                             |
| 8                   | 0.139                    | 0                                 | 0                                 |

| Display time 2 sec   | 4                        | 1                                 | 0.862                             | 0.650                             |
|---------------------|--------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| 5                   | 0.925                    | 0.706                             | 0.451                             |
| 6                   | 0.812                    | 0.437                             | 0.194                             |
| 7                   | 0.601                    | 0.238                             | 0.087                             |
| 8                   | 0.325                    | 0.069                             | 0                                 |

| Display time 3 sec   | 4                        | 1                                 | 1                                 | 0.751                             |
|---------------------|--------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| 5                   | 1                        | 0.997                             | 0.652                             |
| 6                   | 0.989                    | 0.699                             | 0.518                             |
| 7                   | 0.997                    | 0.300                             | 0.249                             |
| 8                   | 0.904                    | 0.198                             | 0                                 |

where $\bar{\ell}$ is the mathematical expectation of the length of the sequence $x$, $\sigma_x$ is a mean standard deviation (m.s.d.) of a random variable $x$.

The assumption of the normal distribution law was tested using statistical criterion $\chi^2$. This criterion allows us to suggest that there is a normal distribution with a significance level of 0.05.

For all experimental conditions, we obtained the dependences of the probabilities of correct reproduction on the length of the sequence for letters of the Latin alphabet, for numbers and characters for different display time. A statistical analysis of these experimental dependencies was carried out. From the analysis it follows that the obtained mathematical dependencies differ significantly at a significance level of 0.05.

Thus, based on the results of the experiments and analysis of the data obtained, we can conclude that:

- the probability of correct reproduction depends on the complexity of the alphabet. The highest probability was obtained for the numbers. A sequence of characters was the most difficult to reproduce;
- the probability of correct reproduction depends on the length of the presented sequence. The longer this length, the lower the probability;
- the probability of correct reproduction depends on the presentation time. The longer the presentation time, the higher the probability of correct reproduction.

Thus, with maximum length of sequence of 8 characters and with presentation time of 3 sec $P_{\text{max}} = 0.904$, when reproducing numbers; the minimum probability $P_{\text{min}} = 0$, when a sequence length is 8 characters and a display time is 1.5 seconds no matter which sequence was presented.
4. Conclusion
A structural model of a human operator in the "human-display" system is presented, which is the basis of the technique for conducting experiments. Methods for measuring visual fatigue of a human operator are considered. It is shown that the method of determining the stability of clear vision is the most suitable for measuring visual fatigue in the "human-display" system. Process of measurement of visual fatigue is automated using this method. The types and characteristics of attention are considered and investigated. A programme that automates experiments to determine the characteristics of voluntary attention is presented. Different types of memory and its main characteristics are considered. Based on the structural model of memory, a technique was developed, and experiments were conducted with a large group of operators (15 people). Results of the experiments showed that the maximum probability of correct reproduction was obtained with maximum length of a sequence of 8 characters and with presentation time of 3 sec $P_{\text{max}} = 0.904$, when reproducing numbers; the minimum probability $P_{\text{min}} = 0$, when sequence length is 8 characters and display time is 1.5 seconds no matter which sequence was presented.

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