Brain-Computer Interface as Tool of Cognitive Optimization (Case of Biases Reducing in Decision-Making and Control Improvement)

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Abstract

This research represents an investigation of cognitive biases in the performance of a typical activity in neuroplasticity training and brain-computer interface literacy development. Research is based on a study of performance metrics during testing and training. The main evaluation indexes are attention, motivation, memory, and perception. Investigation inspired by ideas of artificial cognition and consciousness augmentation trends. For comfortable and clear representation cognitive biases are distributed into four groups by the proposed approach for understanding this phenomenon of cognitive interaction. Results can be used for neuroplasticity training, increasing brain-computer literacy, and sharing useful skills. Research connects with flow and emotional intelligence, human-computer interaction, and decision-making. The experience used in the research based on neuroplasticity trainings tests especially Stroop effect investigation. The problem of control is briefly considered as main factor of cognitive biases. Data collected with Evaluation is made by expert investigation of performance metrics. Cognitive optimization approach is based on previous researches of improving training systems for learning environments.

Keywords

Brain-computer interface, cognitive biases, human-computer interaction, Pearson correlation, neuroplasticity, quantum neural networks

1. Introduction

The brain-computer interface (BCI) makes it possible to optimize one's activities through the development of cognitive skills. Today, neuroplasticity training methods are becoming more and more popular, and monitoring the mental well-being of employees is becoming a real policy of many companies. The spectrum of application of BCI covers the fields of assistive technologies, entertainment, in particular environments with immersive components, the fashion industry, the Internet of the new generation, and education. When making decisions, a person is faced with the influence of cognitive biases. Minimizing the degree of influence of such factors makes it possible to optimize working processes and increase cognitive interaction efficiency. To achieve this goal, special strategies are created, which are implemented in smart environments equipped with the BCI module.

The introduction of special training in the education of students or the internship of employees (decision-makers) is carried out in conditions of decision-making close to professional ones when the decision is made exactly during the duration of a normal response time based on the regular study. The strategy embodies at the same time the planning of professional development or academic success and at the same time tracking the well-being of research participants.

The wide development of BCI at the intersection of many trends in information technology forces us to evaluate the next steps in the development of technology and outline the likely directions and solutions for wide implementations. It is also worth noting the new challenges and problems of using

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such technologies in the predicted conditions. The greatest interest lies in the fascination of the next 20-30 years, and the conditions are influenced by the progress of development technologies and approaches to system design. No less important factors will be the co-alignment in the labor market of different generations and the difference in the ability to use such tools [1;2].

One of the most important achievements of BCI in modern society is the successful suppression of several age-related health disorders (dementia, Alzheimer's disease), disability, schizophrenia, Asperger's syndrome, increased activity syndrome, and attention deficit disorder in children. BCI's achievements in this direction, combined with special practices, are already improving lives, providing opportunities for the full functioning and socialization of millions of people [3;4]. New waves and spheres of interest of BCI have applied studies of consciousness (consumerism, elections, neuroaesthetics), training (success, pleasure), and health surveillance (fitness, yoga, sleep, well-being). The study of the nature of choice and free will in the application to the testing of applied systems increases the efficiency of business and training strategies and develops the functionality of social research and methods of organizing network work and enterprises, improving the quality of products.

2. State of the problem

Judging and decision-making are the main components of most social activity and important factors for system efficiency development. These concepts connected with reason and intelligence so carefully investigated and implemented last decades. The basis of the modern state of we can find in a lot of scientists. In 1906 Charles Spearman proposed a *g* factor for the evaluation of intelligence. His ideas were developed in general intelligence testing in most educational systems. In 1936 Kurt Levin proposed the field theory of social activity. The main point of this approach today is widely used in human-computer interaction, especially the well-known agent-environment paradigm in smart technologies [5]. The scientist described the general rule of activity as:

$$B = f(P, E), \quad (1)$$

where B is behavior represented as a function of P (person) and E (environment).

According the last researches, the view of cognition can be represented in some complex form.[35]

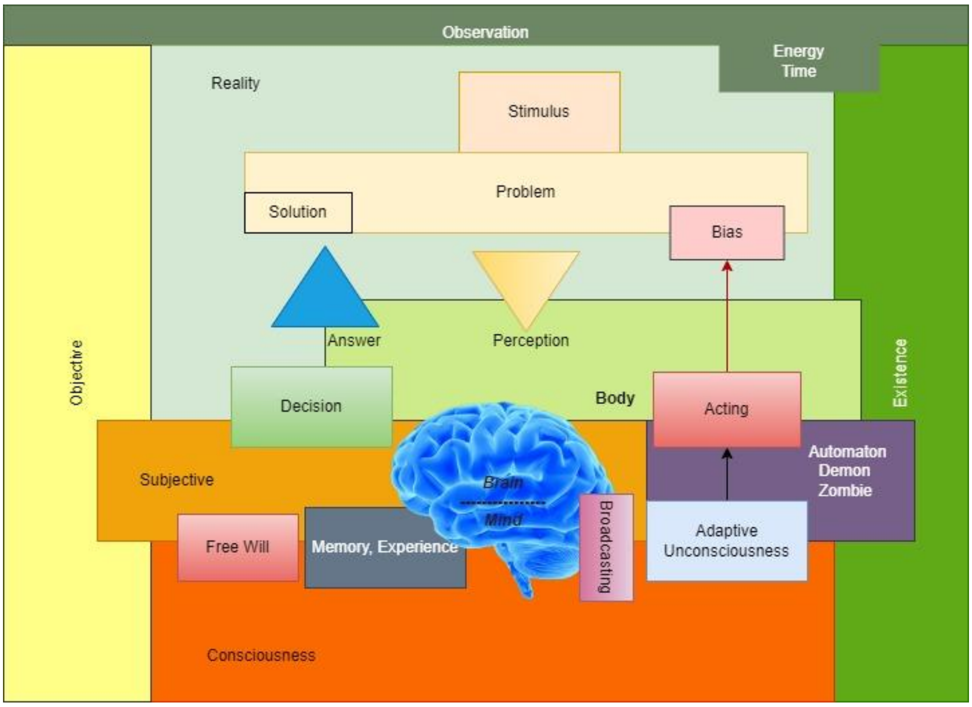


Figure 1. Philosophical vision of cognition

In accordance with observation problem, theory of relativity, hard problem of consciousness, decision-making theory, physical view of reality and the Global Workspace Theory, personal mind is stayed on dynamic state of self-observation, self-control, intention and relaxation, changing depends on external conditions and influencing on reality and environment through body and equipment with constant improving of experience and own abilities.[36]

Any changing of reality and environment can be represented as stimulus or problem for mind, which has own solving (right type of influence, decision) and time for it. Besides, brain has two functional parts (primal brain and cortex[2]), which compete decision-making and thus some answers on stimuli can be fast, but no-right, or right, but not in time etc. This is biased part of problem.[26; 27]

In everyday activity human meet a problem of cognitive biases. Cognitive biases are deviations from wished, logical or right decisions and clear judgements. In general scientists classified 127 separate such biases. Between them are well-known presque vu, overconfidence bias, bias of false attribution, correlation of similar objects, pareidolia, framing, anchoring etc. Most previous researches investigate a few typical cognitive biases. The real state of the problem, that approach for . Improving self-control on different conditions is valuable opportunity since neuroplasticity training strategies become popular. Today there are most widespread in systems with brain-computer interface for workload monitoring.

The newest evolutionary abilities of technologies in intelligence development tend to improve human opportunities in influence on reality and matter. Between them consciousness imitation and upload, which can be implemented on consciousness agents.

2.1. Related Works

Research by Ceschi A. (2018) aims to develop an anti-biased statistical approach as a decision support system for group decision-making (GDM) to detect and handle bias. The paper suggests that these biases conform to a model composed of three dimensions: Mindware gaps, Valuation biases (i.e., Positive Illusions and Negativity effect), Anchoring, and Adjustment. Scientists develop an anti-biased statistical approach, including extreme, moderate, and soft versions, as a decision support system. Between methods, the multiple component analysis and independent component analysis are used for the investigation of participants' problem-solving with previous heuristics and biases studies. Results prove that exploratory and confirmatory analyses yielded a solution that suggested that these biases conform to a described model [6].

This approach and data can be used for similar fields of research and experience design, especially in educational systems. Free will and consciousness interaction in the decision-making process is an important question in neuromanagement and cognitive science. Authors are reviewing a growing argument for unconscious effects on decision-making, which intuitively challenge free will.

Researchers (Mudrik L. 2022) suggest that unconscious influences on behaviour affect degrees of control (reasons-responsiveness). Basic arguments proclaim that there is no certain evidence of the existence of free will in general, but only the degree to which we can be free in specific circumstances.

The unconsciousness influences and awareness in the decision-making process are investigated through samples of routine stimuli on employee subjects within the session designed with special situations conditions features. The approach includes critical reviews of result precision in uncertain conditions and focused on decision-related neural activity preceding volitional actions as the subject of investigation [7]. These results can be used by developers for new systems improvements in ergonomic workspace design as by employees for decision-making process optimization and well-being monitoring. Upon general approaches which determine the theory of decision-making with the purpose for practical use and real implementation of this knowledge, careful attention must be paid to Nick Bostrom's Superintelligence and Russel's Artificial Intelligence. The first work is a very important block for the development of logical prognosis skills and forming of the view of today's situation in intelligence evolution. The second is a successful description of today's state of things in artificial intelligence. This work is actual for each part of our research.

Separately, according to the priorities of this review interests and further development, we should emphasize so important works such as *On Intelligence* (2004) by Jeff Hawkins. The main value of this work is that it helps to clarify the difference between human and machine thinking. Used investigation of the neocortex creates successful modeling of neural activity and describes structural functions of the mind [8]. The ethical issues violated in these works are connected with the required legislation of technologies and implementation of approaches into the work process.

[2] The third on is neocortex. It influences on higher abilities of human mind as wisdom.

William Benzon devotes a separate paragraph to elementary regularities of the cognitive process. It means that simple cognition is a copy of activity in the sensorimotor system located in the temporal lobe of the cerebral cortex. Each node in simple cognition is defined by a sensorimotor scheme. The connecting arcs between the nodes reflect the nature of the feedback interaction between the circuits represented by the nodes at each end of the communication arc. Simple cognition is organized into a musical structure that reflects the number of details in basic schemas, a compositional structure that reflects the volume of schemas, and a syntagmatic structure that reflects the organization of sensorimotor orders.

Computer modeling of processing in a simple cognitive example is a paradigmatic, syntagmatic, and component structure - quite complex. William Benzon emphasizes the rapid development of computer modeling, but notes with disappointment that "computational understanding of system abstraction is but a gleam in the eyes of a very few." The digital computers of the 1970s had a problem. The architecture of the processors of the time was sequential, only one calculation could be performed at a time, while the operation of the abstraction system required parallelism, the ability to perform a large number of calculations simultaneously.

Since nodes in an abstraction system cannot be named, it follows that we can only communicate directly about rationalization. The recasting of rationalization into a real abstract definition involving the functioning of the episodic abstraction system is internalization, as is the recasting of episodes into systemic concepts. The intuitive part of any intelligent organization is likely to reflect the operation of the abstraction system when using its abstract schemas. The hard work of giving verbal form to these intuitions by constructing a statement of first-order abstract concepts is rationalization. Faculty psychology is a rationalization of the activity of the nervous system. W. Benzon illustrates his research with conceptual diagrams [9].

In *The way we think: conceptual blending and the mind's hidden complexities* (2002) by Gilles Fouconier and Mark Turner cognitive networks are presented as metaphorical patterns correlated with the phenomena of human life in society through the study and presentation of hidden or implicit constructions of the mind and the playing of possible situations. Researchers call this model conceptual blending. To achieve quite an understanding of cognitive functionality scientists are using a grand variety of tools proposed by its cross-scientific area and developed new approaches to investigate absolutely new concepts. Upon them, cognitive architectures for creating frameworks, features of cognitive processing and its imitation strategies, phenomena description (such as the hard problem of consciousness), theory of Global Workspace, and cognitive augmentation must be mentioned [10].

Analysis based on cascading cycles of recurring brain events caused by the structure of human cognition is presented in Baars and Franklin's (2015) research. Each cognitive cycle senses the current situation, interprets it regarding ongoing goals, and then selects an internal or external action in response. While most aspects of the cognitive cycle are unconscious, each cycle also yields a momentary "ignition" of conscious broadcasting. Stan Franklin and Bernard Baars used a model of LIDA's cognitive cycle developed with a timing (an initial phase of perception (stimulus recognition), 80–100 ms, conscious episode (broadcast) 200–280 ms, and an action selection phase of 60–110 ms). This model is closely connected with the brain indicating a theta-gamma wave, fixed as a stream from sensory cortices to rostral corticothalamic regions. This wave may be experienced as a conscious perceptual event starting at 200–280 ms post-stimulus. For action selection in the cycle is proposed to use frontal, striatal, and cerebellar regions.

As a result of research, there are two LIDA-based software agents are specified (based on Reaction Time that simulates human performance in a simple task, and the Allport for modeling phenomenal simultaneity within timeframes comparable to human subjects). Research can be implemented in environments with cognitive architecture and approbation of its design [5].

Regression analysis is one of the main approaches for data visualization in the most of researches. Scientists tend to represent some new approach to correlation coefficient understanding and using. Correlation coefficient is the main concept of the major cases for quick and accurate using in statistics. In this research the approach of data analysis connection with theory of global workspace is proposed. The paper (Rodgers J.L. and Nicewander W. A. 1988) presents 13 different formulas, each of which emphasize on a different computational and conceptual definition of correlation coefficient. Each formula suggests a different way of thinking about this index, from algebraic, geometric, and trigonometric settings. The formulas are presented in a way that allows readers to see the connections between them and to understand the underlying concepts that they represent. Results can be used in data analysis especially in correlational analysis and critical skills development [6].

The basis of neuromanagement can be found in Neuromanagement and leadership (Venturella I. et all, 2018). This work describes EEG analysis of the mental activity in organization study according to the newest tendencies of neuroscience analysis in cognitive sciences as well-being and workload through typical human activity

The last neuromanagement achievements are improved by BrainSigns and JLL. The first companies established workload idea with EEG for state recognition technology.

The brain-computer interface (BCI) makes it possible to optimize one's own activities through the development of cognitive skills. Today, neuroplasticity training methods are becoming more and more popular, and monitoring the mental well-being of employees is becoming a real policy of many companies. The spectrum of application of BCI covers the fields of assistive technologies, entertainment, in particular environments with immersive components, fashion industry, the Internet of the new generation and education.

Further development of brain-mediated network mode may concern not only more physical applied networks, but the global and virtual also. The nearer question of technology implementation is how such technology and approach can transform Internet use, especially in databases development and knowledge exchange? Such mode improvised in virtual realities and global network can optimized next development and will have positive influence for common wellbeing.

Anton Nijholt in *Competing and Collaborating Brains: Multi-Brain Computer Interfacing* (2015) describes the features of brain-computer interface applications that assume two or more users and at least one of the users' brain activities is used as input to the application. Scientist used the EEG monitoring approach. Investigation was supported by real-time and off-line processing to analyze and store large amounts of streaming data collected in experiences, which include gaming, entertainment, immersion, and based on the study of control, robustness, and emotion monitoring.

Scientists consider extensions of current applications by looking at different types of multi-user games, including massively multi-player online role-playing games, distinguishing between active and passive BCI on multi-participant BCI in non-game contexts. Research is focused on collaborative and competitive multi-brain games. Important attention is paid to the state-of-the-arts concept in BCI technology and psychological group analysis [12]. These paper results can be used for human-machine interaction and ergonomics research and development in different systems.

Internet of Things (IoT) and brain-computer interface (BCI) are modern emerging technologies. Its combination is more popular last times. The central problems of such decision for user's environments and smart systems are methods of signal processing and sensors sensibility. Researchers (Laport F. at all, 2018) propose to use electroencephalography (EEG) analysis as component of communication interface for BCI implementation in IoT systems. As a model of signal translation the Message Queue Telemetry Transport (MQTT) protocol is used. Proposed method experienced on special study with FP2-channel within 3-day session of users activity and its results represented as α/β ratio of eye movement. Further development of this results can be used for real implementation in Smart Houses and development of applied design methods [13]. There are a lot of real implemented samples of brain-computer interfaces today. A few projects should be named are: a system for car-drive and race (Emotiv and SIMUSAFE), aviation (g.tec and BrainSigns), neuromarketing (Emotiv, BrainSigns, JLL), mental health and self-care (Emotiv, g.tec, BitBrain, NeuroSky, BrainSigns) and advertisement (Emotiv, NeuroSky, g.tec). All these companies have large experience in assistive technologies providing, but they are the ones who inaugurated BCI users' society.

2.2. Cognitive approach in human-computer interaction research

Modelling of custom connectomes has already been implemented by EMOTIV in the BrainViz program. However, there is a problem: cognitive biases as a "knowledge effect" have a rather large influence on training and efficiency performance in regular use (preliminary results of the project "Cognitive optimization system of a smart educational environment with BCI module").

Ethics is also an important issue in development, covering a wide range of ergonomics requirements and a number of regulations and statutory standards. From the mid-1990s to today, the issue of legalization of BCI-society has been widely covered in projects and programs of the European Union Commission, in particular Horizon 2020 and the Human Brain Project.

Great attention to the issue of quality development of neuro-computer interfaces (NCI) is devoted in such fundamental works as Fundamentals of BCI by A. Nijholt, *Clocking the mind* by Jensen A. R., *Toward Brain-Computer Interfacing* by Dornhege G.. An important research method is multi-level analysis in system design [8;14].

3. Session Design

I used the method of evaluating mental activity in the process of decision-making in the conditions of professional activity. The system includes a bank of typical tasks, a module for forming and evaluating the test, BCI and a graphical interface. In addition, voice and tactile input can be provided. In the process of solving tasks, data are collected: educational, mental, cognitive. Educational ones include the type of task object (code, concept, value, set, graph, formula), correct answer option, error, execution time. Primary mental metrics include raw encephalogram, secondary metrics include cognitive metrics such as attention, cognitive stress, and engagement.

Participants are invited to take a test with a set number of professionally oriented tasks within a set time. The criteria for the professionalism of the environment are: the material of the tasks corresponds to professional knowledge, the time to answer a question is equal to a normal response, limited duration of the test according to the ergonomical recommendations (15 - 90 minutes). The research is carried out at workstations with BCI. Collected data includes raw EEG, score of testing, and performance metrics are expertly evaluated by criteria of efficiency (accuracy and reaction time) and workload (control and biases).

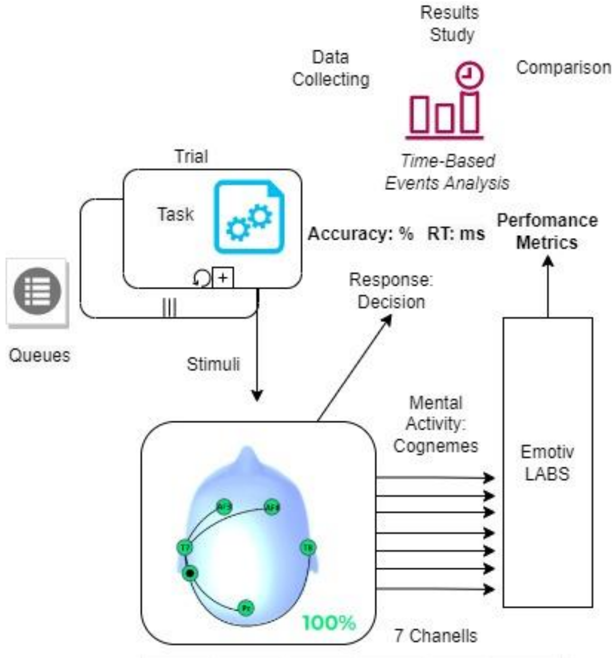


Figure 2: Session Design

3.1. EMOTIV Toolbox for BCI research

For this research I used EMOTIV Insight 2.0 device for EEG biofeedback recording and EMOTIV Labs environment for training sessions and investigation. In this paper I focused attention on typical task for neuroplasticity training and BCI literacy testing based on Stroop effect. These conditions is absolutely satisfactory for cognitive biases investigation and evaluation.

EmotivPRO and BrainViz are software for BCI research, which use all needed tools for mental activity visualization (Figure 4). Above: normal performance. 20^{th} sec of session. State: awake, flow, good attention, normal engagement. Average Reaction Time 623 ms. Band Power for T8 sensor: Theta

– 5%, Beta - 4%, Gamma – 2%. Differences between frequencies powers 0,5-1% (calm mind, flow state). Below: biased performance with mistake. 60th sec of performance.

Figure 3: A – workstation with Emotiv Insight 2.0. B - Stroop test stimulus (screen of session).

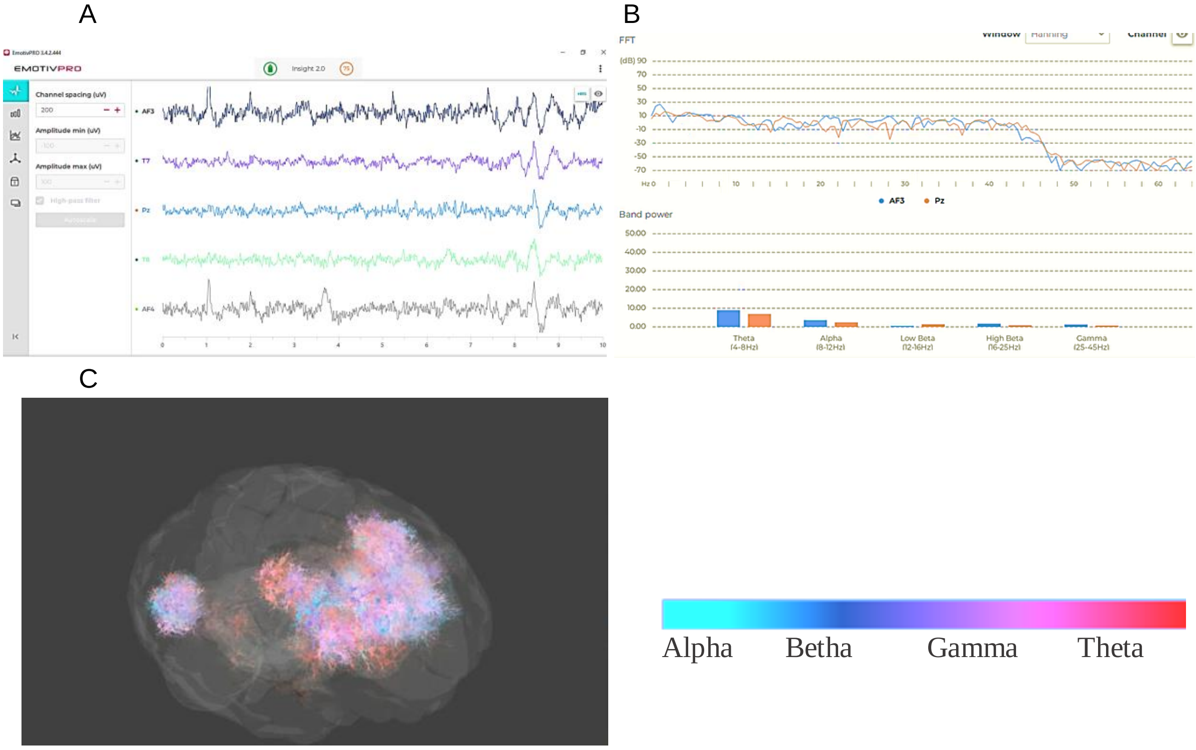


Figure 4: EMOTIV Tools for research. A – real-time EEG. B – Real-time frequency and band power monitor (EmotivPRO). C – real-time brain activity visualization (BrainViz) helps to investigate areas of activity.

Cognitive bias: motivational. Increasing Theta band power (5%) on both Pz and T8 points shows state of resting. May be caused by tiredness. On performance metrics (see below) we can find lost of attention and engagement without increasing of cognitive stress [29]. After session all results are automatically evaluated by comparison with participant age group. The main interest of research is focused on Performance Metrics and training progress of participants.

The opportunity to respond is available during the normal reaction time (RT, 2000-3000 ms). The results are fixed and stored. After completing the test, the participant reviews the tasks a second time in the same sequence and analyzes own answers. The participant indicates whether he answered correctly and which answer is correct, or explains why he did not answer or did not have time to answer, and also provides information about the specifics of decision-making. Ready 120s tests based on collected previous analysis can be very useful. Based on these data, the type of cognitive bias and the degree of its action can be determined by time and intensity indicators (duration of action in milliseconds and change in indicators of involvement or concentration). Then the answers are compared, the complete picture of the test is determined [25]

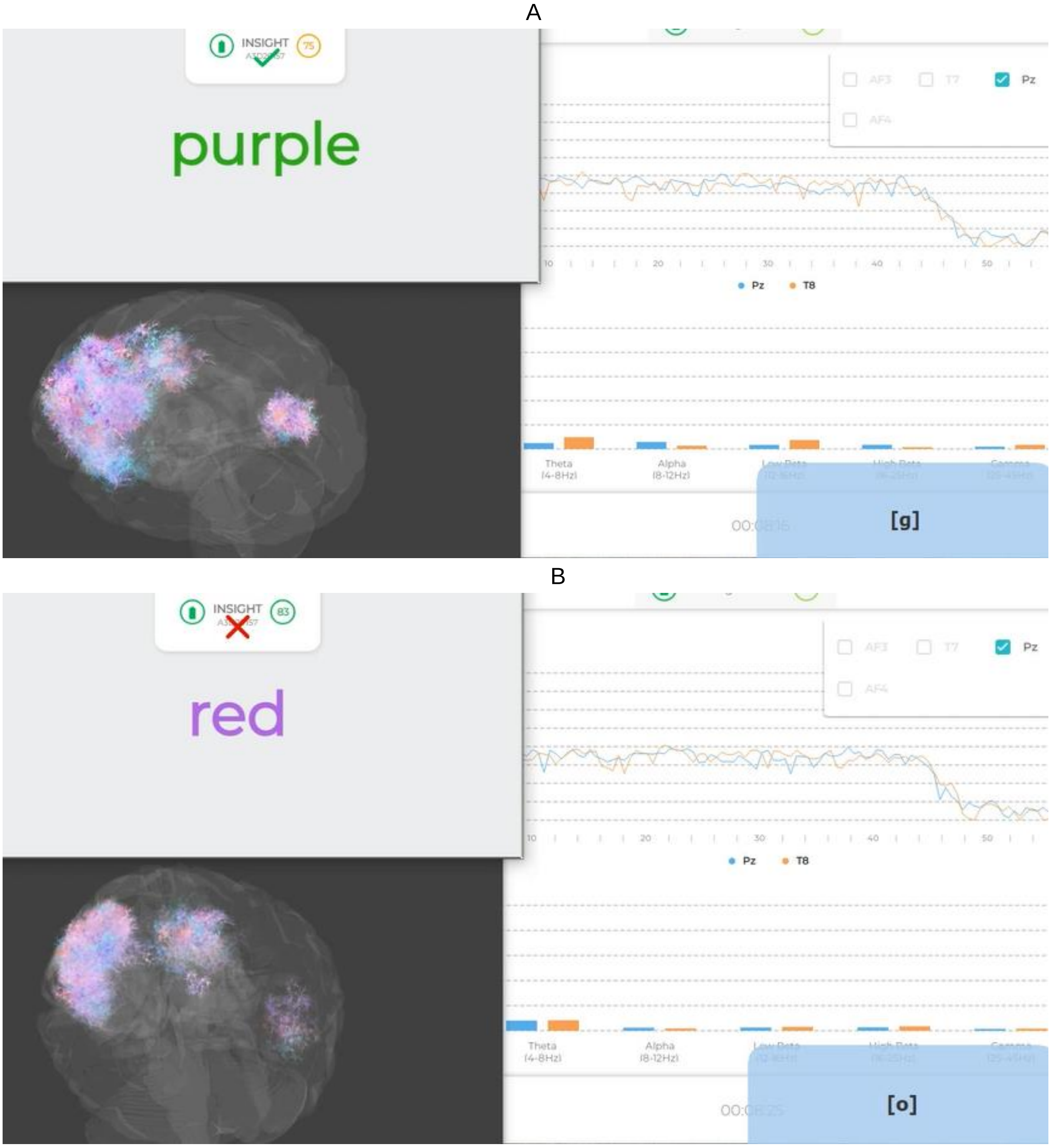


Figure 5: Session. Stroop test training.

Bandpower. Activity regions. Above on blue shadow moment of bias (60th sec of performance, Figure N). Below: training session progress with detailed statistics.

Each task represented as trial with designed stimulus and response types classified separately. The introduction briefly explains the type of tasks and questions. Time windows are also explained there. Fixation stage aimed to study the normal EEG of participants in the beginning of the experience [26] Decision-making process can be represented as response result, which is fifth

$$D =< S, R, RT, Acc., PM >. \qquad (2)$$

where S is stimulus, R is response, RT – response time, Acc. – accuracy, PM – performance metrics. Stimuli must be collected in special collection and responses must have relation to these collections in the database.

Reaction time, accuracy and performance metrics available on user's profile in EmotivLABS community. Stage of problem solving can be represented as temporally complex perception and decision-making or judging process during stimulation with the response as its result:

$$t_S = t_P + t_{Ac} + t_D + t_R \quad (3)$$

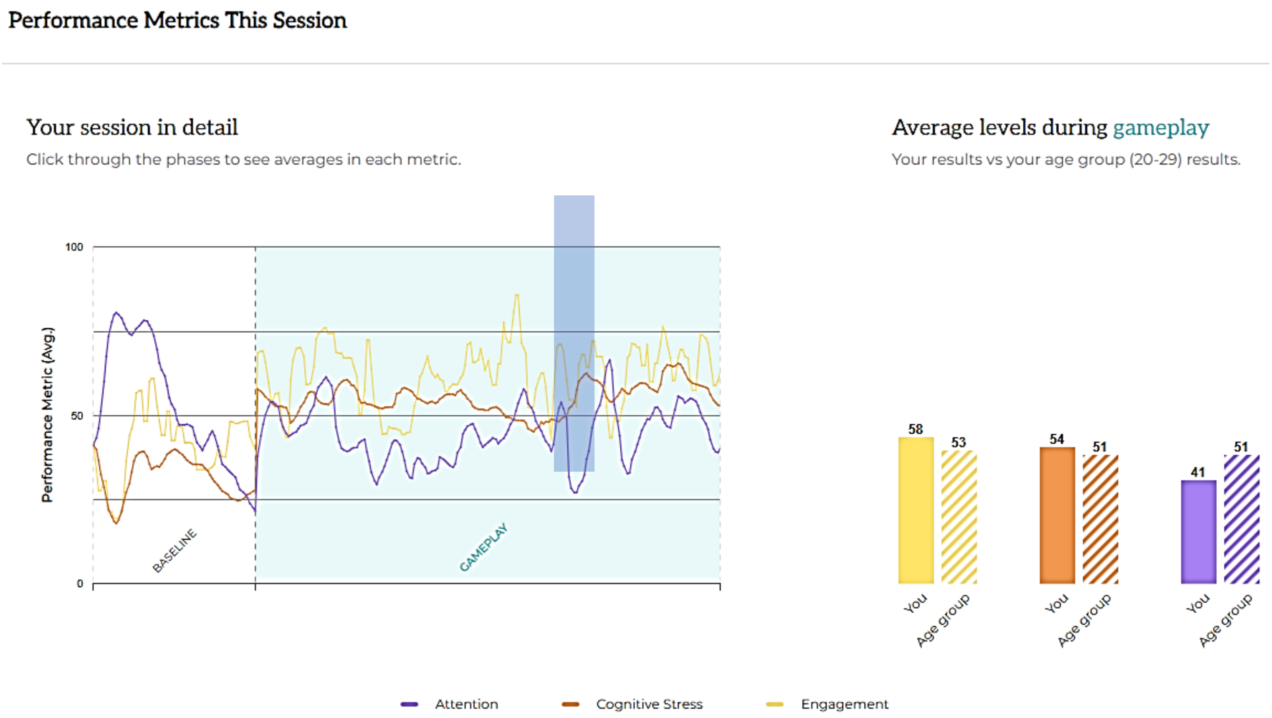
$$R < r_1, r_2, \dots r_n > \quad (4)$$

$$\textbf{if } R = r_i \textbf{ then } Acc.++ \; else - \quad (5)$$

$$r_i \in R_a, \quad (6)$$

where R is a set of answers, and R_a is a subset of correct answers.

A



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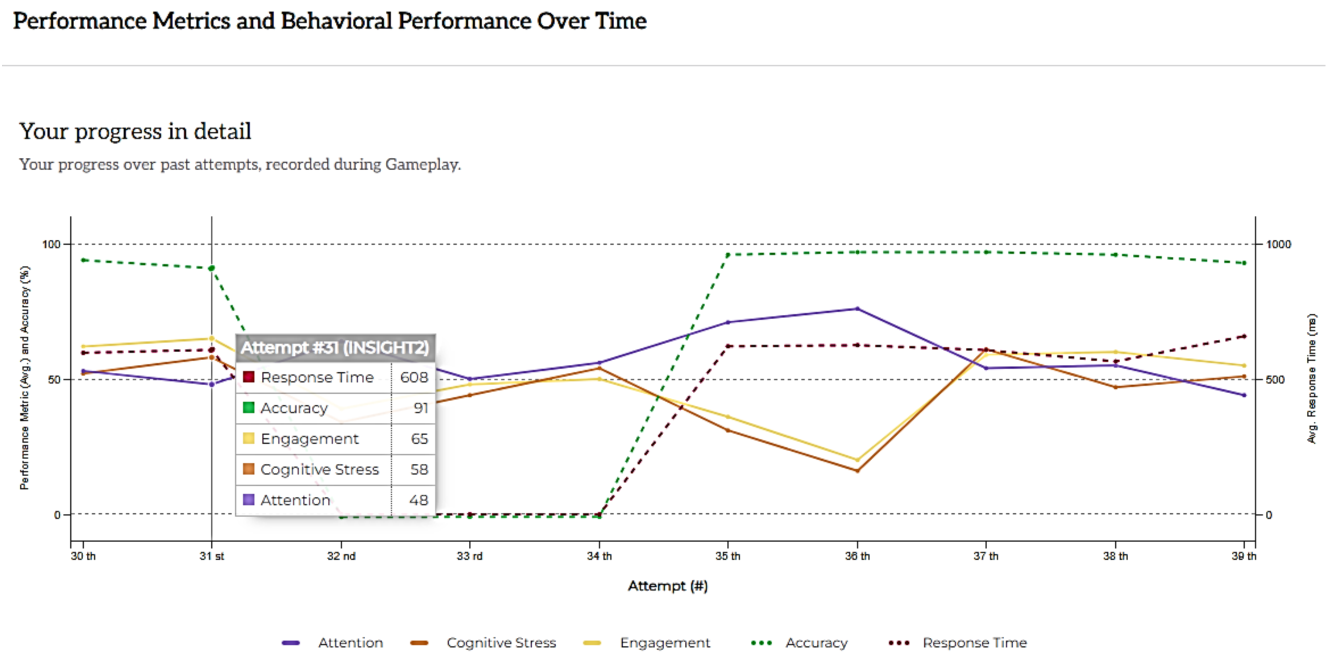


Figure 6: Study of cognitive metrics of performing applied neuroplasticity training tasks using the Emotiv Insight 2.0 headset.

Cognitive biases are deviations, which can be detected as fourth

$$CB = <R, RT, Acc., PM> \quad (7)$$

where *R, RT, Acc., PM* are all the same as previous, but lower in comparison with normal. One of these forth is enough to detect cognitive bias. Also, cognitive biases can be represented as *CB* = <*CBr CBrt CBacc. CBpm*> (8), with its own indexes [21; 20].

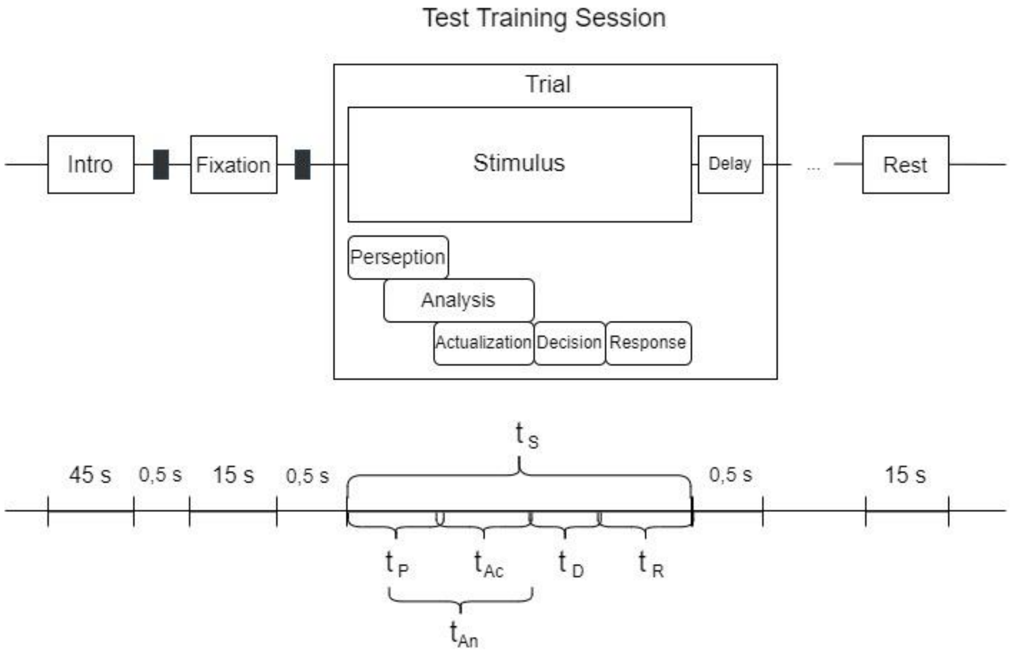


Figure 7: Session design.

Biasing of performance has its own determination. It is the relation between four groups of biases (Figure 9). For generalized representation biases can be collected in table.

In this research, I used noninvasive portable electroencephalograph Emotiv Insight 2.0. This device detects EEG on AF3, AF4, T7, T8, and Pz sensors. The methods of ERP recognition, independent component analysis, and support vector machine are used for collecting biofeedback data as real-time EEG and Performance Metrics, which help to investigate dynamics of such features of biofeedback as affection, attention, tiredness, engagement, cognitive stress, rest, and exciting.

First column represents the equipment and software used for sessions and data collecting. Second is generalized process view with data description (where Acc. is for accuracy, RT – response time, PM – performance metrics (attention, engagement, cognitive stress), PM2 – emotional performance metrics (excitement, focus, relaxation). Questioner 1 is questions about subjective evaluation of current state. Questioner 2 is subjective evaluation of own performance, which helps to fix overestimating of confidence type of biases (motivational). ERP (event-related potentials) – technology used for computation of RT and PM changes according to actions (key inputs). Convolutional neuronal networks and Support Vector Machines are used in EMOTIV Labs for PM decoding from rawEEG inputs. P300 paradigm is used for ERP detection. Output data collected in .csv or .xls formats. Pavlovia framework can be used for sharing results. PsychoPy environment is comfortable for professional sessions design.

To investigate the effect of cognitive biases, an analysis of performance metrics is carried out with the marking of points of influence and the evaluation of the degree of action. Marking is based on participants answers. The degree of action is described by the duration and intensity of the factor. A qualitative characteristic is a group of cognitive biases.

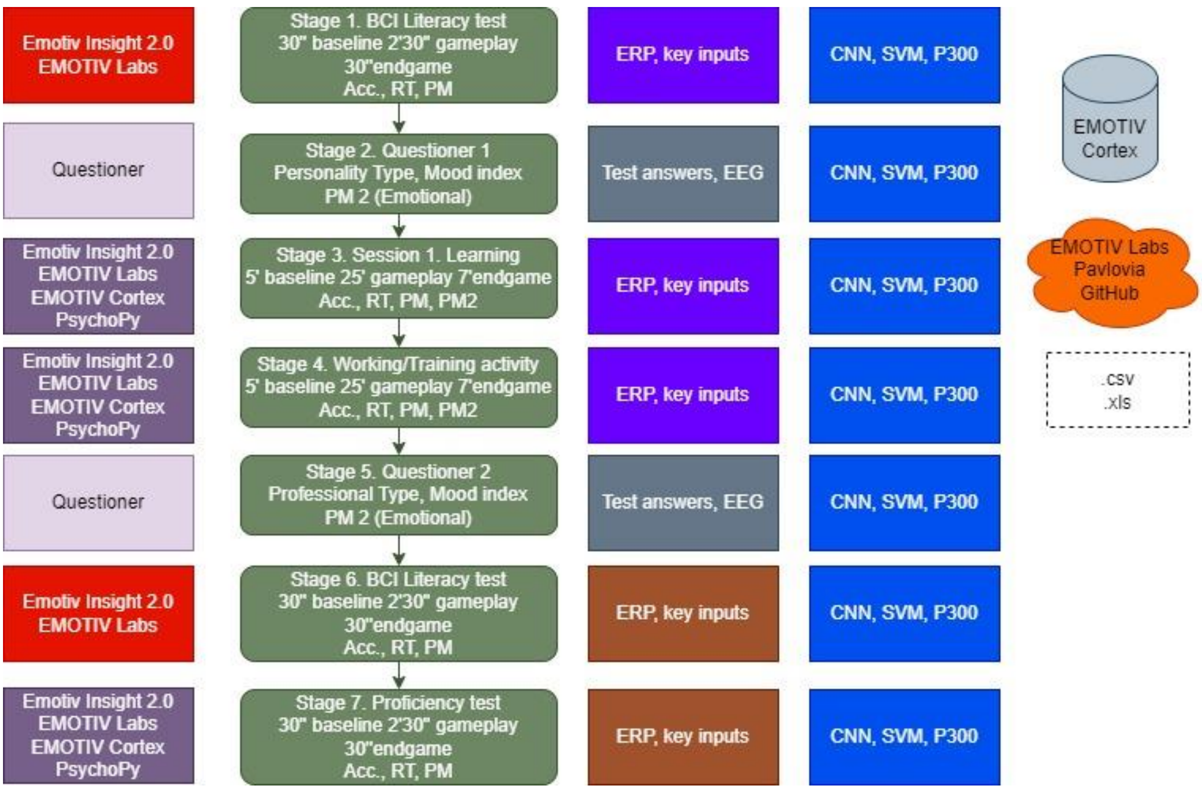
For example, pareidolia belongs to the perception group, and framing belongs to memory biases. The intensity of cognitive bias is defined as the ratio of the normal value of the characteristic indicator (attention, involvement) to the factor affected by the action. For each session, I use additional testing before the performance and after the session. These tests include evaluation of EEG, band power of waves, brain activity, and emotional and performance metrics during 1,5 – 0,5 min. Also, I use questionnaires for performance [33].

The influence of cognitive biases can be evaluated by typical indexes of the session as reaction time, accuracy, and performance metrics.

$$CB_{RT} = \frac{RT - RT_{norm}}{RT_{norm}},\ CB_{RT} = \frac{RT - RT_{norm}}{RT_{norm}},\ CB_{RT} = \frac{RT - RT_{norm}}{RT_{norm}}. \quad (9)$$

Table 1
Table title

Bias Type Description	Examples	Reasons	Representation
Perception Non-adequate perception of stimuli	“R” for green “red” in Stroop test Cluster illusion	Need for fast answers, incorrect performance prioritization[3]	Associative variants Increasing engagement, loosing of attention
Attention Deviation of results or errors because of lack of attention and focus	Concentration on form against quality	Tiredness, effort, brain inertia[4]	No answer in time Incorrect answer Loosing of attention Low engagement
Memory Non-adequate or absence of results	Loosing details, incorrect calculation or comparison	Tiredness, effort, need to rest, unconscious cycles, lack of time	No answer in time Incorrect answer Low engagement
Motivation Loose of control and flow, apathy, boredom	Fast unemotional pressing keys without immersion in task and performance	Loosing of flow state, depression, stress	No answer in time Incorrect answer. Participant don’t remember situation. Hight cognitive stress Low engagement. Low attention



Dataset model

Stimuli	Acc.	RT	Attent.	Engag.	Cog.Stress	Q1	Q2	Q3	Q4	Q5
[1,…,8]	[0.01,…0.99]	[0.180,…,1.5]	[0.01,…0.99]	[0.01,…0.99]	[0.01,…0.99]	[1,…,5]	[1,…,5]	[1,…,12]	[1,…,15]	[1,…,n]

Figure 8. Data collecting process and technologies.

[3] For training sessions, each participant must have correct instructions. It is proclaimed by the idea of cognitive organization of any smart environment and means a standard action chain with determined priority. For the Stroop test, it is two unprioritized conditions. Namely: the answer is pressing the key signed for the stimuli word color in RT diapason or faster. In performance participants' brains act fast and correct, feel time and recognize color. At the same time semantics (word) is precepted faster than color. The participant must refrain from pressing the key connected with the meaning of the word and focuses on color.

[4] Hypothetical concept based on effect of saving state in changing conditions with repeating actions, competing brain network activity.

Тест №	1	2	3	5	6	7	9
Опис	Code	Value	Graphics	Formal	Term	Value	Array
Тип	a	a	b	c	f	c	d
RT ms	889	675	753	659	821	743	650
Accur.	0,99	0,99	0	0,50	0,99	0,50	0,99

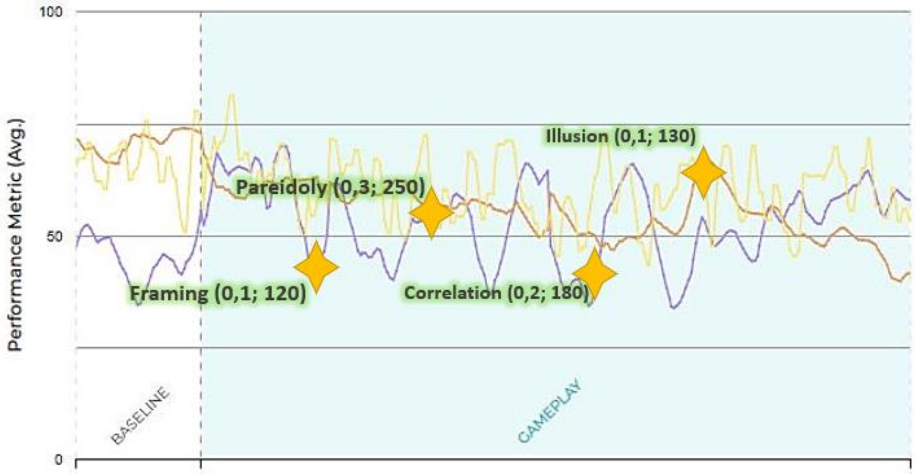


Figure 9: A model for determining the effect of cognitive biases by degree and duration and marking performance metrics.[5]

These indexes can be compared with the efficiency of the system for investigation of its implementation and the prognosis of its evolution. [19; 22]

We have the problem of the impossibility of ideal performance as an observation problem. Anybody can't imitate an absolutely clean performance. My further research interest includes investigating this phenomenon with imitated performance. Realization of this task foresees the development of a cognitive environment with artificial consciousness or using the LIDA model.

Quantum neural network.

In our case of decision making and biases is connected with hard problem of consciousness, mind-body problem and brain entanglement it would be actual to use quantum cognition architectures for the system design. To perform classification task for performance metrics evaluation in decision-making process with biased states a variational quantum circuit with rotation operator gates and free parameters can be used (Figure 10).

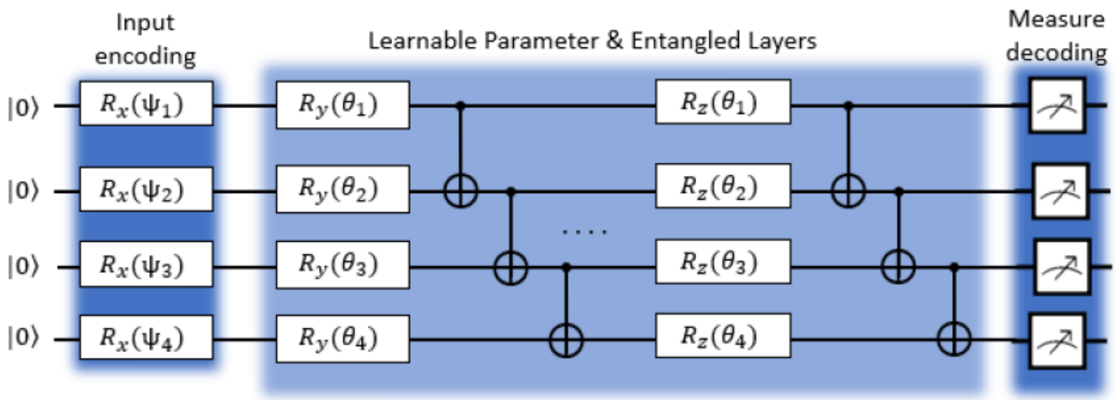


Figure 10. Quantum neural network can be used for efficient system design.

In quantum computation $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \|\alpha\|^2 + \|\beta\|^2 = 1$ is a two-dimensional complex vector normalized representation for a single qubit state, where $\|\alpha\|^2$ and $\|\beta\|^2$ are the probabilities of observing $|0\rangle$ and $|1\rangle$ from the qubit, respectively. Geometrically represented using polar coordinates

[5] Data Table of Performance Metrics compared with Data Table Testing by time.

θ and ϕ as $|\psi\rangle = cos(\theta/2)|0\rangle + e^{i\phi}\sin(\theta/2)|1\rangle$, $0 \le \theta \le \pi$ and $0 \le \phi \le \pi$ for mapping the qubit state into the surface of Bloch sphere. A multi qubit system can be represented as the tensor product of n single qubits, which exists as a superposition of 2^n basis states from $|00 \ldots 00\rangle$ to $|11 \ldots 11\rangle$. Quantum entanglement appears as a correlation between different qubits in this system. For example, in a 2- qubit system $\frac{1}{\sqrt{2}}|00\rangle + \frac{1}{\sqrt{2}}|11\rangle$, the observation of the first qubit directly determines that of the second qubit. Rotation operator gates $R_x(\theta), R_y(\theta), R_z(\theta)$rotates a qubit state in Bloch sphere around corresponding axis by θ and controlled-X gate entangles two qubits by flipping a qubit state if the other is $|1\rangle$. Network can be developed in acceptance of studied conditions and changed separately to problem solving with cognitive biases for improving quantum cognition algorithms which are comfortable for such problems modeling [37].

4. Results and Discussion

The next stage is to explain cognitive biases to participants and demonstrate their actions. After that, students pass tests with training to overcome the effects of cognitive biases. The results are recorded and compared. Collected factors for evaluation are represented as paired data $\{(x_1, y_1), \ldots, (x_1, y_1)\}$.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}}. \quad (10)$$

I visualize the results of the evaluation by emphasizing positive and negative effects with a range of correlation scales from weak to strong accepting $r_{xy} \in [-1,1]$. The final results are presented in Fig. 11. Collected during the investigation data are represented in the same table.

Positive **Negative**

	Perfomance Metrics						Results		Cognitive Biases				
	engageme	exitemen									m	CB p	Er
engageme	1	-0,0559	0,644918	0,082158	-0,12587	0,205005	0,350854	0,211451	-0,03871	-0,0511	0,389968	0,183497	-0,43355
exitemen	-0,0559	1	-0,2507	0,578352	0,108253	-0,6758	-0,45661	-0,20336	0,653532	0,752051	0,425803	0,583194	0,189509
attention	0,644918	-0,2507	1	0,009165	-0,42666	0,364133	0,577791	0,744991	-0,49826	-0,55215	-0,15241	-0,24669	-0,7226
cog. stress	0,082158	0,578352	0,009165	1	-0,32409	-0,81771	-0,44368	0,324871	0,651685	0,681013	0,202724	0,7483	0,18917
relaxation	-0,12587	0,108253	-0,42666	-0,32409	1	0,104595	-0,0719	-0,76956	0,105802	0,144866	-0,00866	-0,05436	-0,02614
focuse	0,205005	-0,6758	0,364133	-0,81771	0,104595	1	0,707731	-0,00551	-0,77941	-0,75762	-0,4301	-0,7526	-0,48703
accuracy	0,350854	-0,45661	0,577791	-0,44368	-0,0719	0,707731	1	0,156902	-0,83693	-0,75545	-0,57058	-0,74973	-0,87199
RT	0,211451	-0,20336	0,744991	0,324871	-0,76956	-0,00551	0,156902	1	-0,22234	-0,34182	-0,19462	-0,01628	-0,28198
CB a	-0,03871	0,653532	-0,49826	0,651685	0,105802	-0,77941	-0,83693	-0,22234	1	0,93214	0,603255	0,952479	0,701777
CB mot	-0,0511	0,752051	-0,55215	0,681013	0,144866	-0,75762	-0,75545	-0,34182	0,93214	1	0,560034	0,867028	0,60515
CB mem	0,389968	0,425803	-0,15241	0,202724	-0,00866	-0,4301	-0,57058	-0,19462	0,603255	0,560034	1	0,628384	0,481457
CB p	0,183497	0,583194	-0,24669	0,7483	-0,05436	-0,7526	-0,74973	-0,01628	0,952479	0,867028	0,628384	1	0,589062
Er	-0,43355	0,189509	-0,7226	0,18917	-0,02614	-0,48703	-0,87199	-0,28198	0,701777	0,60515	0,481457	0,589062	1

Strong Middle Weak Middle Strong

1 0,9 0,6 0,3 -0,3 -0,6 -0,9 -1

Figure 11: Correlation matrix of training indicators and the activation of cognitive biases according to individual results.

The evaluation was carried out according to the indicators of cognitive metrics (concentration, excitement, relaxation), performance (concentration, involvement, cognitive stress). Learning outcomes were assessed by reaction time (RT), accuracy and error rate (Er). Cognitive biases are classified by groups: biases of attention (CB a), motivation (CB mot), memory (CB mem) and perception (CB p). The introduction of technology based on the example of advanced companies in educational activities allows students to develop the skills of effective adaptation to modern working conditions and increases the effectiveness of education. Expanding the power of research (complex tests, several stages of processing results, adaptation of test programs to the system of curriculum studies) will become a stage of mastering neuroplasticity as a new type of competence. To implement this approach you should describe your task, select stimuli, formulate questions (or trust it to chatbot), create psychological tests, and, sure, classify terms used for responses and tasks design. Then you will use this system with participant and through enough time you can collect biases and heuristics for training design.

In my research the strongest correlation was between attention, perception and motivation pairs. Correlation rate between memory and others groups of biases were middle (Figure 12).

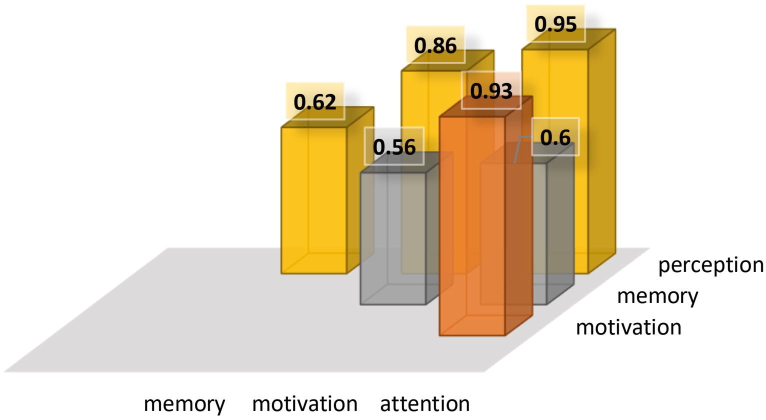


Figure 12: Correlation between different groups of cognitive biases in Stroop test

Sure, this research is just introductive and very selective because of specific character of such investigations, technical conditions of equipment and software, possible condition of conscious observation and psychological features, but I suppose as it is valuable path in this field as these results will be useful for further researches and development of cognitive optimization of complex systems and human-computer interaction.

The main achievement of this research is new approach, which implement opportunity for evaluation of wide range of cognitive biases immediately. Previous researches mostly concentrate own attention on certain number of most popular cognitive biases, ignoring less important. Most of researches use special conditions and simple testing problems. Proposed approach is more universalized and can be implemented as for learning as for working and professional environments and conditions, carefully including individual features of mental activity recognition of each attendee.

Further development and implementation. Artificial part of interaction can be evaluated on efficiency by index of biasing as human part of interaction. In this case we should and general evaluation will help to evaluate index of efficiency of cognitive interaction.

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