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Darya Momotenko

PSYCHOPHYSIOLOGICAL FEACURES OF EXECUTIVE FUNCTIONS DURING TYPING ON A COMPUTER

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Gorbunov Ivan Anatolievich

_____(Signature)

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Introduction

The study was conducted at St. Petersburg State University in the Laboratory of Multidisciplinary Studies of Human Development supported by the RFBR grant № 20-313-90046\20 from 13.09.2020, the head of Grigorenko E. L. L., who was the Academic Supervisor the graduate school until the termination of her labor relations with SPSU in 2022. The dissertation research is aimed at studying executive functions in computer typing.

Written speech is a form of speech associated with the expression of words using graphic symbols. Written speech is arbitrary because it involves analysis and synthesis both grammatically, phonetically, and syntactically. As computer technology advances, written speech becomes increasingly prevalent, and in some professions, it can almost completely replace oral speech. For example, children as young as 6 years old can type search queries for children's channels on tablets or phones [102], and older adults are beginning to learn new methods of communication in social media [102]. The widespread proliferation and use of keyboards has elevated the automated typing skills of ordinary users to the level of experienced stenographers [123]. Thus, research on typing on computers and alternative devices is becoming relevant these days. The results of such research canbe applied in various practical areas, ranging from clinical diagnosis of speech or cognitive disorders to the development of neurointerfaces - devices that help respondents control computer programs without muscular activity [68; 108].

Most of the works on the psychophysiology of typing can be divided into three groups. First, they answer the question of how the central and peripheral parts of the nervous system are interconnected in typing. Research in this area is aimed at developing various theoretical and mathematical models of typing [118]. The second block of research includes works examining inhibitory and activation processes in the brain in different ways of typing [58]. The third block of research, the most common in the literature, is thestudy and development of non-traditional ways of typing, such as brain-computer interfaces, touch keyboard typing, or typing with oral sensors [118].

Given the prevalence of typing skills in the modern world, the study of this phenomenon can provide valuable information about the levels of hierarchical work of neurophysiological systems in the formation of skills and conscious regulation of activity, i.e. about the executive control of activity [93]. Herein lies the **relevance** of the research. A relatively recent theoretical review of current research on executive functions [1] illustrates that despite an extensive body of research conducted on samples of elementary and middle school-aged children as well as older adults, there is an extremely limited amount of research from young and middle adulthood.

The **subject** of this study is executive functions: processes of working memory functioning, executive control, as well as processes of switching and inhibition.

The **object** of the research are neurophysiological markers of executive functions during typing.

The **aim** of this study is to determine neurophysiological correlates ofexecutive functions during typing.

In order to realize this aim, we set the following **tasks**:

1. Determine the structure of relationships between behavioral indicators of executive functions as measured by psychological techniques.

2. Determine which behavioral characteristics of typing (e.g., speed, accuracy, number of errors) can act as an additional factor in models of executive functions in typing.

3. Evaluate the contribution of level of executive function developmentto behavioral characteristics of computer typing.

4. Evaluate contribution of level of working memory, inhibition and attention switching to features of functional brain state, expressed in spectral characteristics of electrical activity during typing of memorized text.

5. To evaluate the contribution of the level of development of executive

functions in the process of sentence formulation to the peculiarities of the functional state of the brain, expressed in the spectral characteristics of electrical activity.

6. To compare functional state of the brain expressed in spectral characteristics during copying and formulation of sentences.

Based on the above, we can formulate the following research hypotheses:

There is a model that can describe the variance of activation power of alpha, beta and theta rhythms during typing on the computer throughthe level of executive functions, working memory and inhibitory processes, measured by the BRIEF method.

This study plans to use two techniques to examine executive function: the respondent's level of executive function development was assessed using the BRIEF-2, Behavioral Rating Inventory of Executive Function, Second Edition (BRIEF-2; [48] and the Universal Nonverbal Intelligence Test (UNIT-2, Universal Nonverbal Intelligence Test, Second Edition, [22]. This choice is mediated by the fact that the literature recommends assessing executive function with a combination of questionnaires and techniques. The study also conducted two psychophysiological experiments aimed at copying and sentence formulation. An electroencephalogram (EEG) was recordedduring the experiments.

The **novelty** of the research consists in studying the direct dynamics of psychophysiological processes, reflecting the work of the hierarchical system of executive functions during typing. This approach is not seen in the list of available sources. The hierarchical system of interaction consists of individual elements that function in a one-to-many relationship [93]. Nevertheless, the cognitive processing processes in this hierarchy may not be hierarchical, but rather run in parallel [64]. For example, when typing, the mechanisms of sentence formulation and word typing may be performed at the same time, because these activities engage different mental processes and brain regions. Accordingly, this issue requires more in-depth study in terms of the psychophysiology of typing.

The **practical significance** of this study is that free typing can be universally applied both in the diagnosis of various kinds of speech and motor disorders, and inthe development of modern technologies, such as brain computer interfaces. According to the research, EF contributes greatly to the typing process, and an important step towards their research would be the development of specific experiments to study them, which would include additional assessment of IF with the help of techniques and questionnaires. At present, quite a lot of literature is devoted to brain computer interfaces. Such studies study neuronal activity in different ways of information input (typing on a touchpad, using a keyboard, etc.). Most often participants are asked to copy a given text or to formulate individual sentences. We did not find any brain computer interface studies that used free-formtyping. Since free speech is most often encountered in everyday life, it is so important to consider its features in the development of newer technologies, such asbrain computer interfaces, as well as in diagnostic tasks.

Reliability and approbation of the results

The validity of the results is ensured by the correct use of statistical methods (including the use of corrections for multiple comparisons) and careful control of factors. We used the following methods of controlling variables: 1) random assignment of participants to groups; 2) randomization of stimulus presentation within each of the experiments; 13 4) automation of stimulus material presentation and recording of measured indices.

The results of the experiments were discussed at the following scientific conferences:

- Daria Momotenko with the report "Psychophysiology of executive functions in the process of typing on the computer" at the All-Russian Forum of Psychologists of Russia, September 28-30, 2022

- Daria Momotenko with online report "Working memory during typing: EEG study" at the international conference "Neurowissenschaftliche Nachwuchskonferenz" in 2021.

- Daria Momotenko with online report "Predicatory capacity of beta activity during typing: assessing the level of language development" at the 20th World Congress of Psychophysiology in 2021.

To summarize, we can say that typing is an example of multilevel functional cognitive activity, which involves a complex of mental processes, including the EF, i.e. executive control, working memory and cognitive flexibility. Accordingly, the study of typing can be one of the ways to study these phenomena. Particular attentionshould be paid to the study of the psychophysiology of typing, since such works canprovide valuable information about the realization of hierarchical systems in the brain.

Provisions put forward for defense

1. The higher the level of development of the skill of inhibition of the nervous system, and, as a consequence, the more effective the work of inhibitory processes, the higher the accuracy of the printed sentence.
2. When copying a memorized sentence, activation of alpha, beta and theta rhythms is observed. Beta rhythm illustrates the process of information processing and issuing motor commands, while alpha and theta rhythm show the balance of inhibitory and activation processes. In the interaction of these processes during typing, a model of motor working memory can be observed.
3. During the formation of the automated printing skill, participants with high executive control free resources for the realization of other cognitive tasks, thereby expanding resource-intensive working memory and reducing cognitive load. This is demonstrated through an increase in alpha rhythm in participants with high executive function, and an increase in beta rhythm in participants with low.
4. The difference in beta rhythm may suggest that copying complex, meaningless

sentences that require a high resource load, according to working memory theory, is less likely to activate the beta rhythmicity that occurs during complex tasks. According to the available data, the appearance of theta activity in the frontal-medial area during text copying indicates a general increase in cognitive load during the printing process.

Chapter 1: Psychophysiology of executive functions during on acomputer.

1.1. Executive Functions: Definition and Classification.

One of the founders of the study of voluntary regulation of purposefulbehavior is A.R. Luria (1970) [5], who in his works was engaged in research of functional disorders of the control and programming block of the brain. This block combines both the motor component of programming and realization of movements,and its regulatory component, which is responsible for the correctness of theexecuted action.

Currently, there are several translations of the term "executive functions" in Russian literature, which came from foreign literature. In particular: "executive functions" (Alekseev, Rupchev, 2010; Vilenskaya, 2019, Gracheva et al., 2008; Nikolaeva, Vergunov, 2016; Pushina, 2014; Chukhtova et al., 2011), "controlling functions" (Alfimova et al., 2009; Velichkovsky, 2009; Machinskaya, 2015; Semenova, Koshelkov, 2009) and regulatory functions (Veraksa, Gavrilova, Bukhalenkova, 2019).

The researchers define executive function (EF) as the ability to retain information in working memory and inhibit automatic responses to external stimuli [1]. EF form the basis for intentional executive control of behavior [12]; [27] and are also involved in processes such as emotional regulation, planning, and decision-making [78].

There are currently numerous studies investigating executive functions, withopen questions regarding their definition, functions, localization, and measurement. Nevertheless, it is possible to identify some basic characteristics and functional components of EF based on an analysis of the literature [27]; [78]. Executive functions involve high-level cognitive processes aimed at planning and anticipating events. The cognitive skills that fall within this framework include emotion regulation and thoughtful decision-making [12]; [78].

In contemporary Russian studies, EF are also defined as a set of cognitive functions aimed at purposeful and adaptive behavior. Moreover, there are numerous studies highlighting the importance of EF development during adolescence, which is a sensitive period for the prefrontal cortex's formation [1]. A recent theoretical review of

EF research [1] suggests that there is a considerable amount of research on elementary and middle school-aged children, as well as older adults, but limited research on young and middle-aged adults.

EF are involved in information reception and processing, as well as action implementation. There are currently three popular theories that describe the processof EF functioning: the theory of attention networks by M. I. Posner and Peterson S. E. (1990), the model of Miyake A. [81], and the three-component model proposed by A. Diamond [41].

1.1.1 Classification of EF

The research on executive functions began with the classification of attention networks by Posner M.I. and Peterson S.E. (1990). They suggested that attention systems are anatomically separated from information processing systems, similar tothe sensory and motor systems. They also localized attention networks in the brain,based on the cognitive functions involved in activating these networks. They identified three networks: (1) orientation toward a sensory stimulus, (2) alerting: conscious processing of a fixated signal, and (3) executive: retention of concentration, or the stage of readiness for action.

The orientation network involves shifting processes and is localized in the posterior parietal lobe and partially in the thalamus. This was confirmed by observations of monkeys given chemical injections in the corresponding areas and by depression of these areas in patients with attention switching process disorders [90]. In a subsequent review, Petersen and Posner (2012) demonstrated that a common set of right hemisphere and thalamic areas are primarilyinvolved in stimulus detection in some studies, while left hemisphere brain mechanisms are involved in others. These differences may reflect variations betweenhemispheres, in which lateral processes are often slower effects (tonic), and left hemisphere mechanisms are more frequently associated with higher temporal (phasic) or spatial frequencies.

The stimulus fixation system, later known as the executive attention network [90], is responsible for the process of stimulus recognition andprocessing. It includes monitoring of the surrounding processes, selection of a specific stimulus that is considered as the target. The authors also note that a separateanatomical structure is required for more accurate differentiation of various stimuli,which may be located in the anterior cingulate cortex and dorsolateral prefrontal cortex. This is also confirmed by other studies [45]. These structures also include language processing, which allows for a separate emphasis on the executive control system, which will be discussed in more detail below.

The last attention network in this classification is the alerting system, which allows attention to be maintained on a more priority stimulus and provides for a rapid response. It includes tasks of semantic classification. That is, in this system, both information accumulation and maintenance of a state of constant readiness occur. Most of the research appeals to the right hemisphere, the middle frontal cortex, which was also demonstrated in studies of patients with impairment of this function.However, it should be noted that all three systems are closely interrelated. In a laterclassification [90], this attention network was also linked to working memory functions.

1.1.2. Miyake's Model of Executive Functions

The three-dimensional model developed by A. Miyake [81] is frequently cited in literature as the basis for understanding executive functions (EF), which are believed to be located in the frontal lobe. EF were originally studiedand categorized through the examination of patients with frontal lobe damage or cognitive impairments. Diagnostic tools such as the Wisconsin Card Sorting Test (WCST, [109] and the Tower of London task [91] were used to assess these impairments, as well as to determine the level of fluid intelligence. However, individual differences led to varying results and difficulties in diagnosing EF, necessitating the development of an empirically-testedclassification system.

The three-dimensional model developed by A. Miyake [81] consists of three components, namely inhibition, updating, and shifting [12]; [99]. The inhibition component involves executive control, which is defined as the ability to consciously regulate automated or impulsive thoughts and actions [12]. Specifically, it refersto the ability to consciously suppress dominant automatic responses when necessary. The Stroop task [55] is a well-known example of aninhibition task, where one must resist the urge to name the color of a word that is written in a different color. This type of inhibition is typically associated with the frontal lobes [81]. It is important to note that the concept of inhibition used here is limited to intentional, controlled suppression of automated responses and does not include reactive inhibition or a reduction in activation due tonegative weight association. Tasks used to test inhibition abilities include the Strooptask [110], antisaccade task [53], stop-signal task [71],and go/no-go task [44], all of which require conscious inhibition of an automatic response, with the specific response to be inhibited varying across different tasks.

The second block is the switching block, or as some researchers define it, the cognitive flexibility process block [41], is related to a person's ability to switch between tasks, thoughts, and actions, as well as consider different perspectives and maintain goal-directedness and selective attention [12]; [41]. If this function is examined in more detail, it canbe said that it involves rejecting an irrelevant set of tasks, followed by switching to relevant ones [81], or in other words, proactive interference of negative priming. In the aforementioned Posner and Petersen model [90], visual attention focused on the temporal area was also featured. In this case, switching between tasks is related to mental effort and cognitive load, which is regulated by the anterior cingulate cortex, reflecting the attentional orienting network. The tasks that the authors used to determine switching are plus- minus tasks, number-letter tasks, and local-global tasks.

The third block - the updating - is associated with working memory, which is responsible for storing and processing current information, as well as actively manipulating information and filtering necessary information in a specific situation[81]. Another function of working memory is filtering necessary information in a specific situation [12]. The localization of working memory, according to A. Miyake's model, is usually associated with the dorsolateral prefrontal cortex, while the functions responsible for passive storage and retention of information are more localized in the premotor areas of the frontal cortex. Tasks that can measure working memory include tracking tasks, N-back tasks, memorization of sequences, and monitoring background.

The researchers divided executive functions into three blocks: switching, updating, and inhibition, and examined statistical differences between them. However, the authors acknowledge that these functions are not entirely independentand may have internal correlations. There are two possible reasons for the correlationbetween these functions. Firstly, they all involve controlling information processing,which could unite them. Secondly, they may all use inhibition processes for normaloperation. Therefore, it could be assumed that the correlation between switching, updating, and inhibition may be due to their shared requirement for information processing control and inhibition processes. However, further research is needed to fully understand the reasons for the correlation between these functions. Diamond (2013) provided a more comprehensive description of executive functions, identifying three main ones: executive control, working memory, and cognitive flexibility. Each of these will be discussed in more detail.

1.1.3. Definition of Working Memory

One of the main components of cognitive function is working memory, which involves the processes of holding and manipulating information in mind (or, in other words, working with information that is no longer present in perception; [11], [107]. Working memory is a complex set of mentalprocesses by which a limited amount of information is held in a state of temporaryavailability for cognitive processing [36]; Baars & Gage, 2014).Working memory can be divided into verbal and visuospatial working memorybased on its content [41]. Working memory is involved in processes ofperception, recall, processing, production, and comprehension of information, as it requires holding in memory what happened earlier and relating it to the current agenda. Thus, it is involved in understanding the meaning of oral and written language, performing mathematical calculations, ordering objects, planning, considering alternatives, as well as analyzing and synthesizing information.Working memory is also involved in thinking, finding relationships between objectsand events, extracting elements from the general picture, and solving creative tasks. The most common methods for studying working memory are tasks involving repetition of numbers or words in reverse or altered order, tasks for finding the mostefficient route, tests of visual-spatial memory (such as UNIT-2), and the N-Back task in different modalities.

At present, there is still no comprehensive classification of memory [28]; however, the most commonly used classification distinguishes between long-term, short-term, and working memory [38]. The fundamental difference between long-term and short-term memory lies in the duration of storage of encoded information. In addition, long-term memory stores a large reserve of knowledge about the past experiences of each individual [37], whereas short-term memory stores information for a brief period oftime, such as retaining sequences of numbers or words. Thus, working memory canbe defined as having similarities to short-term memory, but possessing the functionof processing and manipulating information [9], [10].

1.1.4 Working Memory Models

The multicomponent working memory model proposed by Baddeley and Hitch performance [28] suggests that working memory is a complex system that consists of multiple components, including a phonological loop, a visual-spatial component, and central executive control. The phonological loop is responsible for processing and storing verbal information, while the visual- spatial component handles nonverbal information. The central executive control serves as the supervisor of the system, directing attention and coordinating the different components. The episodic buffer, added in the later version [8] of the model, serves as a temporary storage space for information from different modalities model.

On the other hand, Cowan's (2008) [37] model views working memory as a component of short-term information storage that is dependent on attention and executive functions. In this model, working memory is integrated with long-term memory, and the interaction between the two types of memory is hierarchically structured.

Overall, both models offer valuable insights into the functioning of working memory, and they have contributed to our understanding of how we store and process information in real-time.

1.1.5. Neurophysiology of Working Memory.

Many researchers believe that the prefrontal cortex is responsible for the neurophysiological basis of inhibitory control [67]. Studies on working memory have shown that Broca's and Wernicke's areas are activated by verbal and acoustic information, while visual-spatial information is processed in the right hemisphere [11]. However, more recentresearch suggests that working memory topography is located in the frontoparietal lobe, which includes the dorsal-prefrontal cortex, parietal cortex, and cingulate gyrus[28] or general neural network activation.

For example, the dorsolateral prefrontal cortex is often involved in tasks of executive control [60], information integration or decision-making [56], information processing [98], or information updating processes [83]. In turn, the cingulate gyrus is responsible for attention-switching processes, which is also involved in correcting and adapting received information [88]. The parietal gyrus isconsidered as an area of storage and processing of sensory and perceptual information [28].

Nevertheless, studies have also shown that the activation of working memory involves the functional activation of the whole brain [28]. However, neural network studies have also shown bidirectional endogenous connections between the aforementioned areas in the frontoparietal cortex [46]; [77].

Furthermore, research has demonstrated that deeper structures, including the basal ganglia [82], mediodorsal thalamus [19], midbrain [83], and cerebellum [124] are also involvedin working memory processes, which also illustrates the whole brain working in working memory activation.

1.1.6 Definition of Executive Control

Executive (inhibitory, inhibitory, or cognitive) control is viewed in the literature as the ability to control and regulate one's attention, behavior, thoughts, and emotions in order to overcome an internal stimulus or external stimulus in orderto perform a purposeful and conscious action [41]. Executive control allows one to suppress attention to other stimuli by focusing attention on a specific task. The most illustrative example of how this function works can be seen in the "cocktail party" effect, where the respondent consciously focuses attention on only one stimulus, ignoring all others. Often executive control is measured through accuracy and reaction speed in multiple-choice tasks. Such tasks might be the Strooptest [55], the go-no go task [44], the Simon task [36], [24], the Flanker task [61] or antisaccade tasks [18].These kinds of tests, which require inhibitory (or inhibitory) control, are excellent illustrations of executive function. They demonstrate the ability to focus on a specific, most meaningful task and to ignore all other, incidental stimuli. For example, in Stroop's task, the respondent is asked to read a word without paying attention to the color of the ink. Appealing to typing processes, a vivid illustration of this process would be correcting the word, that is, removing the printed word. Therespondent must follow the semantic content of the text, correcting errors in the process [106]. And, while the process of typing itself can be conditionally automated, that is, higher mental functions will not be involved in this process, error correction obviously requires activation of mechanisms of inhibition and executive control [43].

It is important to note that executive control affects all stages of typing, from sentence formulation to direct typing. The cognitive effort expended in writing depends on the skill level of the user. When writing by hand, more proficient writersexpended less effort [30]; [95]. Thus, the automation of handwriting in adults allows them to activate high-level writing processes (planning, processing, and editing what they have written) at the same time as writing [17]. The same principle holds true for keyboarding [58].

When it comes to the neurophysiology of executive control, the prefrontal cortex areas have an important control function in the brain. The prefrontal cortex isresponsible for highly organized goal-directed behavior [1], of which hierarchical executive control is part. The processes of goal setting, planning,monitoring, and outcome assessment are included requiring activation of executivecontrol at each stage. Studies [26]; [30]; [117] show that when executive control is activated, beta activity can be observed in the dorsolateral prefrontal cortex, in the cingular cortex. In the case of spatial search, in the parietal cortex [55].

1.1.7 Definition of Cognitive Flexibility

Cognitive flexibility is also a basic executive function that emerges much laterin ontogenesis [41]. Its main areas of manifestation are the ability to look at a problem from an alternative perspective. This can be manifested both within one individual, i.e. looking at the problem from a different perspective, non-standard approaches to solving the problem, and interpersonally, i.e. as the ability toaccept another's point of view. It should be noted that both working memory and inhibition are involved in the processes of cognitive flexibility, as earlier evolutionary processes.

Cognitive flexibility (cognitive switching, attention shifting) is an individual's ability to switch between two or more different tasks, to easily change perspectivesin space (the ability to see a flat image as deep) or interpersonal communication (theability to see a problem from a different perspective) [35]. Cognitive flexibility is an essential ability to assess and adapt current psychological operations and to appropriately coordinate the distribution of cognitive processes in dynamic decision-making environments [66].

Another aspect of cognitive flexibility is the ability to adapt to the changing circumstances of the environment, to adjust their behavior, depending on the priorities of the situation, as well as the ability to take advantage of new, unexpectedopportunities. Cognitive flexibility involves creative approaches to problem solving,as well as a high ability to switch, which is mediated by a rapid change of focus of activity [66]. Special emphasis should be placed on the fact that cognitive flexibility is involved in determining what specificcognitive resources are required for the task at hand. First, the decision maker needsto be able to describe the type of problem he is facing, which requires identifying different elements, perspectives, and perspectives of the situation. Second, he needsto consider the various possibilities, which requires active reflection on the elementsidentified in order to find possible connections and assess their relevance. Finally, cognitive flexibility can be used to switch between these processes when solving problems [66]. Also, cognitive flexibility is involved in understanding one's own limitations when making fact-based decisions[126].

Cognitive flexibility in psychology is usually investigated with different typesof paradigms on the switching of attention between tasks: Attention Neural NetworkTest (ANT), the Stroop test, the task switching paradigm or dualtask paradigm, etc. These classic cognitive flexibility paradigms require switching or coordinating cognitive processes to successfully complete the task at hand. Scores in such paradigms assess the ability to coordinate attention processes between two or more parallel or alternating tasks. Such tasks measure the "cost of switching" - the increase in reaction time when switching between tasks compared to a situation without switching.

Tasks on verbal, semantic fluency are also methods of measuring cognitive flexibility. These kinds of tasks are used in creativity tests. For example, a participant needs to name unusual ways of using an object (a pencil), come up with a sentence,each word of which will begin with the letters PRAI, name the maximum number of characteristics of an object in a limited time. An important aspect of the Cognitive Flexibility Tasks is that the more time a participant thinks about a task, the more unorthodox solutions can be presented. Also included in this block of tasks are visual fluency tasks. That is, the participant must draw the maximum number of objects that have a circle or find objects in a noisy picture [41].

There are also standardized techniques for studying cognitive flexibility. For example, the already mentioned Wisconsin Card Sorting Test [112], which aims to categorize cards according to a certain attribute. Another example is the dual decision tasks, which, on the one hand, monitor attention-switching processes (tasks on shape, color, or location of a figure). In this case, the task that the participant performs changes with each subsequent presentation, and each stimulus simultaneously has multiple features that respond to both the previous andthe next task [23]. It is important to note that the fundamental difference between cognitive flexibility tasks is the content component. That is, theparticipant is offered some new set of items, or a fundamentally different rule for their selection. This allows one to measure the speed of decision-making, rather thanthe working memory capacity needed to implement it.

This kind of test was developed by Zelazo and colleagues (2003), the key difference of which was only one switching between tasks. That is, the stimuli werealso bivalent, but sorting was conducted only according to one law. This test is muchmore illustrative for preschool children because it is more difficult for children to remember instructions when task switching is high. The following explanation of this phenomenon has been suggested. Because in children, activation in the dorsolateral prefrontal cortex is first determined by the previous test rule [119], children have difficulty overcoming "attention inertia," the ability to focus attention on something that was not previously relevant, which is associated with subsequent response inhibition. Moreover, with age, a similar kind of inertia can also be observed in the difficulty of switching between tasks [41]. Regardless of task difficulty, when an additional stimulus is added, task speed increases [23]. This has been tested on sortingtasks, ambiguous figures, or the Flanker task. Cognitive flexibility shows the extentto which the participant is able to switch between mental tasks of different orientations and overcome inertial tendencies.

Some authors [23] describe cognitive flexibility as a meta-control of executive functions. To expand on this idea, cognitive flexibility is seen as a higher-order process, and conscious switching between tasks promotes adaptivebehavior. Most studies show that the prefrontal cortex is actively involved in the processes of cognitive flexibility, particularly in the differentiation of attention resources when assimilating a particular signal, that is, switching attention to a stimulus [97]. However, research shows that thalamic structures are also deeply involved in these processes, suggesting a hierarchical structure of cognitive flexibility. The mediodorsal thalamus reads preliminary "cues" from the external environment and regulates prefrontal representation switching, which provides a computational framework for thalamic involvement in cognitive flexibility [97]. In other words, the hierarchical structureof cognitive flexibility has been confirmed in mouse experiments. Thalamic structures are selective to the content of cues, which provides a contextual representation of the incoming signal to the prefrontal cortex.

A meta-analysis on the neurophysiology of executive functions [85] demonstrated that the prefrontal, premotor, parietal, inferior temporal, and occipital cortices as well as subcortical structures such as the thalamus are involvedin cognitive flexibility processes. Stopping further, the prefrontal cortex is includedin the processes of switching between tasks, as well as tracking context to implementthe processes of inhibition. Since studies show that the ventrolateral prefrontal cortex is activated both during inhibitory control and in cognitive flexibility tasks that involve task switching. Accordingly, it can be assumed that either the task rule response set is updated, or the previous response set is inhibited.

1.2 Theoretical Foundations of Typing

Typing is a complex process that engages both cognitive and motor functions.An analysis of speech production alone is insufficient to form a unified theory of the development and functioning of speech skills in writing. In cognitive research, typing is most often studied by assessing the cognitive load associated with differenttyping conditions. For example, in a study conducted by Burle et al. (2016) [26] ,respondents who had no opportunity to correct errors in the text were more successful. They had a higher typing speed and made fewer errors. There are severalconditions for reducing the cognitive load of typing and making it automated, including typing without error correction [26], using a familiar keyboard [121], and having the skill of blind or semiblind typing [93].

When typing is not automated, there is an additional cognitive burden. The process of speech production becomes more complex, not only due to the motor effort required to type words but also due to the cognitive effort needed to find specific letters on the keyboard. These cognitive processes engage spatial reasoning,executive attention, and working memory [47]; [64]; [93]. In automated typing, cognitive functions may not be involved, and typing will be driven by mechanical memory.Thus, the hierarchy of text formulation and realization processes in typing proceedsautonomously, and the activity becomes more productive. Despite the recognition of the role of working memory in typing, modern cognitive research has not yet presented a comprehensive study of the information flow in typing [6].

One of the main questions that arises in most studies is related to the role of the central and peripheral nervous system in prin ting. Some researchers believe that typing occurs in stages, which means that the central and peripheral departments function autonomously and sequentially transfer control over typing to each other. Other authors suggest the existence of a hierarchical relationship between the two, in which the central departments correct the work of the peripheral systems throughout the typing process [16]; [54].

1.2.1 Two Feedback Loops Model

The prevailing theory of typing processes is the two-feedback loop model, which describes the specific properties of word processing [39]. This model is based on hierarchical control of cognitive processes in typing [47] and provides a comprehensive understanding of the neurophysiology of typing on a computer. The external loop is responsible for sentence formulation, while the internal loop is responsible for its direct implementation in typing. The external loop starts with speech comprehension or formulation and ends with the generation of words to be typed. The internal loop starts with the acquisition of the word to be typed and ends with the sequence of keystrokes

[39]. In contrast, earlier models, such as Rumelhart and Norman (1982), focused more on the motor component of typing, including finger motor skills. According to this model, typing is a complex activity that involves sequential actions controlled by motor programs, which are assembled intohierarchical circuits [21]. Typing requires control of finger movement, shoulder position, and forearm position for both hands [100]. Moreover, planning movements for each key and combining them into motor patterns to type a word requires parallel information processing [74]. Sequential inhibition processes occur during typing, wherein the movement associated with typing the first letter is activated first, and allsubsequent movements are inhibited [86]. After typing the first letter, the motor pattern is rearranged, and the movement associated with the next letter becomes active. Thus, there is a sequential congruent system of global activation [100]. Although the motor mechanisms of typing have been extensively studied, there is no unified theory that describes all stages oftyping, from sentence formulation to motor realization of movements during typing.

1.2.2. Neurophysiology of Typing

Miller's TOTE system [80] proposes a mechanism for controlling the conscious activity of typing, which is still relevant today. This mechanism involves four stages: test, operate, test, and exit. The TOTE mechanismis analogous to the process of stopping the back propagation of an error. For instance,when typing the letter "Y", the goal is to print the letter, and a checkup is performedto compare the actual state with the desired one (i.e., the position of the finger relative to the Y key). If the actual state differs from the desired state, the differenceis reduced by moving the finger. The process is repeated until the goal is achieved or the task is modified due to an error. If an error is made, such as typing "C" insteadof "Y", the TOTE mechanism restarts, and the typing sequence is modified to correct the error. When errors are corrected during typing, the TOTE mechanism becomes hierarchical, indicating the transfer of information from the outer loop to the inner loop. Overall, the TOTE system provides a useful framework for understanding thecontrol of typing as a conscious activity that requires consistency and control.

1.2.3 Working Memory during Typing

The theoretical framework of this theory is also consistent with a block of resource theories. For example, a model proposed by several researchers [14], which suggests that the cognitive load and amount of working memory required to implement a task is a product of the processes of switching anddistributing attention between these tasks. That is, the more attention resources an individual has, the greater the amount of working memory he can engage, the allocated cognitive resources ensured the success of a given task.

In this paper, we plan to test the performance of these models in typing. The important contribution of working memory to the typing is indicated by the fact that working memory is one of the key elements of the writing. Working memory, including typing, is viewed as a set of mental processes through which a limited amount of information is held in a state of temporal availability to serve cognitive activity [37]. The task of data transformation in typing requires the engagement of working memory as a buffer for storing, processing, and transferringinformation. Two types of working memory models can be distinguished within which the writing process is described. Resource models, as described by E.L. Grigorenko (2012), separate the processes of text generation, i.e. selection of lexical and syntactic structures, and the processes of transcription, i.e. spelling and writingdirectly [12]. These models include the concept of resource allocation [30] between mental processes, according to which a more difficult task loads working memory more heavily [30]. Whereas, the speed of information processing increases with the automation of typing processes. The higher the skill of automatedwriting, the faster the processes in working memory.

The alternative component models [28] described above suggest that there are separate domains in working memory responsible for different cognitive processes. For example, the planning process is associated with visual working memory, text structuring involves the spatial component of memory, and phonological memory may be responsible for direct writing, i.e., converting text from spoken to written text.

1.2.4. Executive Control in the Typing Process

Recent studies on executive control have demonstrated that even automated actions can involve activation of executive control, particularly when habitual actions are disrupted or errors are made [58]. For example, when a typist makes an error in typing, executive control may be activatedto correct the mistake. Similarly, when an individual experiences a broken arm, previously automated movements need to be consciously controlled to restore habitual functioning. Additionally, when there are changes to a familiar route, cognitive realignment becomes necessary, requiring a switch between automated and conscious activity.

Voluntary control of movements operates through hierarchical control, which involves a one-to-many relationship between independent elements that organize the hierarchy, as illustrated by the sequential process of typing letters, words, phrases, sentences, and texts [72]. However, the cognitive processes involved in this hierarchy can also be non-hierarchical and simultaneous, such as the processes of sentence formulation and word typing during typing, which involve different mental processes and brain areas. As a result, a sentence can be fully formulated before the motor response process catches up with the speed of sentenceformation.

1.2.6 How to Study the Neurophysiology of Typing?

The number of researches on the neurophysiology of typing is limited [47]; [39], and there is still much to learn about theneural processes involved. Additionally, the potential practical applications and diagnostic possibilities of this knowledge are still unknown. However, some studies have been conducted to address this issue. Electrophysiological studies using EEG have shown activation of both the ipsilateral and contralateral motor cortex before key pressing [24]; [26]; [47]. Othermethods such as magnetoencephalography [30], transcranial magnetic stimulation [42]; [123], and functional magnetic resonance imaging [70] have also confirmed activation of the ipsilateral motor cortex during movement realization. Additionally, research has found that the ipsilateral motor cortex activity increases as the response produced becomes more complex [47]. The EEG has recorded decreased excitability of the ipsilateral motor cortex as a positive component that appears before the motor response and is seen as anticipation of theresponse [123]. Contralateral and ipsilateral activity can be modulatedindependently of each other in experiments evaluating the difference in response time between left- and right-handed typing, and they are believed to be distinct processes [26]. In the following sections, various print study methodswill be discussed to determine the most appropriate methods for examining the EF.

1.2.7 Evoked Potentials in Typing

The analysis of movements during typing involves two main evoked potentials (EPs), namely the conditional negative variation (CNV) and lateralized readiness potential (LRP). The early wave CNV is considered to be an orientation response to a warning signal, while the late CNV is believed to reflect the preparation of the motor response, which is identical to readiness potential (RP). LRP is an EP recorded in the motor cortex in response to movement onset, and it captures the lateralization of EEG activity generated by activation of a specific response arm [64]. LRP amplitude provides insight into spatial or temporal features of an upcoming movement, such as the direction of movement orthe response arm [89]. LRP is commonly used in typing studies because it can reflect inhibition and activation processes in the typingprocess.

When studying EF in the brain during typing, inhibition processes are necessary to maintain hierarchical control over sequential key presses [123]. Inhibition should reach its maximum before the first keypress, and letters thatare to be typed with a particular hand are inhibited during typing with the other hand[65]. If one adheres to the hypothesis that motor response preparation is realized before typing begins, inhibition processes are necessary to maintain hierarchical control over sequential key presses [65].Inhibition should reach its maximum before the first keypress, when the summationof activation signals for all subsequent keys of the target word occurs [93]. In two-handed typing, letters that are to be typed with a particular hand areinhibited during typing with the other hand [72]. Thismechanism involves inhibition of opposing cortical structures ipsilateral to the hand making the movement [123]. The researchers [123]concluded that regardless of the hand used to print, the amplitude of the LRP willdecrease with each successive letter pressed. However, the amplitude from the handthat first proceeded to type will be greater than the amplitude from the second hand.Working memory can also be studied with LRP. This capability allows predicting the sequence of keystrokes during typing. One study [16]demonstrates that typing relies on parallel processing when pressing keys. In theexperiment, participants were presented with a word and then required to type aspecific letter. When the required letter was present in the primed word, it was typed faster, illustrating how working memory functions in typing. The location of theletter in the word had no effect on the response speed. An analysis of the LRP amplitude [63], recorded before the first press of a key duringtyping, showed that the amplitude was higher when all letters in a word had to betyped with one hand. The amplitude decreased as a function of the number ofswitches between hands. This also confirms that type planning (formation of motorrepresentations) takes place before typing begins.There are also studies demonstrating the high predictive validity of the LRP for determining the typingsequence of letters when typing with two fingers on a touch keyboard [100]. Such research may offer new perspectives on the development ofneural interfaces, which are currently most often based on the P300 potential arising in response to a novel unfamiliar stimulus [84].

Overall, LRP is a productive tool for studying typing because it directly relatesto the set of letters, and it can provide insight into the spatial or temporal features ofan upcoming movement.

1.2.8 Spectral Evoked Potentials in Typing

Various studies have investigated the use of spectral EPs in typing, with motor response preparation being expressed as oscillations in the beta frequency range (15-30 Hz) [13]; [123]. Event-related desynchronization in thebeta frequency range has been observed during the preparation of manual movements [59], while spectral potentials associated with word or sentence typing have been recorded bilaterally between 400 ms and the onset of movement, particularly when three or more keys are pressed sequentially [40]; Krueger et al., 2019). This effect is thought to indicate a general level of motor training prior to word typing, although some studies view this effect as both inhibition and activation depending on the taskcontext [80]. Negative spectral activation potential isregistered in the motor cortex contralateral to the effector and corresponds to typingthe correct answer in the experimental task, while positive activation potential indexes the inhibition of the ipsilateral motor cortex responsible for suppressing erroneous responses [39]; [114]. In addition, beta-band activity is linked to cognitive load during typing and executive control [69], making it possible to compare the effects of activation and inhibition on motor response preparation by studying spectral potentials.

1.2.9 RAW EEG Analysis in Typing

There are limited studies in the literature on the RAW EEG analysis during typing [118]. Existing research focuses on detecting spectral activity, coherence, or connectivity during writing to determine the level of cognitiveload during typing [104]; [118]; [63]. Theta activity in the frontal-medial region during text copying indicates an increase in cognitive load during typing, while resynchronization in the parietal and occipital regions in the range of theta and alpha rhythms, appearing after sensory typing, indicates resource allocation [79]; [118]. Additionally, the analysis of baseline EEG during typing can be useful in the diagnosis of dyslexia, as unique patterns of brain activity are observed in children with dyslexia in the anterior frontal zone [102].

Although some studies have examined cognitive load during free typing, the EF is not well studied using EEG Analysis [105]. Given that typing is a complex hierarchical process that fully engages the EF, such studies would be highly relevant.

1.3 Summary

The literature review reveals several groups of experiments focused on investigating typing and related problems that can be examined from the perspectiveof exploring the psychophysiology of executive functions. However, there is currently a lack of standardized experiments for studying the role of the EF during typing [6]. Therefore, it is essential to incorporate methods and questionnaires specifically designed to assess the EF into the experimental design when exploring this phenomenon.

Executive control

Studies that focus on one- or two-handed word copying aim to analyze the motor circuits that are formed during the automation of typing and to investigate theactivation and inhibition processes that take place during the execution of motor commands [47]. By using the word copying task as an example, it is possible to describe how the EF functions within the two feedback loops model [72]. The outer feedback loop reads and processesthe stimulus, while the inner feedback loop transmits the typing commands for a given word, which are then divided into individual symbols to implement typing. Each symbol corresponds to a specific motor pattern, which is expressed through a key press. In similar experiments, it is possible to analyze both EP and backgroundEEG to study the inhibition and activation processes of the nervous system.

The study of error correction during typing can provide insights into executive control, as discussed by Kalfaoğlu, Stafford, and Milne (2018) and Śmigasiewicz etal. (2020). The process of error correction involves two loops: the inner loop, whichrelies on feedback from hand movements to determine whether a key has been pressed correctly, and the outer loop, which relies on information displayed on the screen to determine whether a word has been typed correctly. This process demonstrates how executive control operates on the central departments to guide the peripheral ones. Additionally, the appearance of the graphical pointer (GP) in response to the "Backspace" key and during error correction can be used to measurethe respondent's IF values and illustrate executive control.

Error correction can be seen as a way of implementing executive control, sinceit involves receiving negative feedback from the periphery. This feedback can be received in two ways: either the respondent sees the error on the screen and correctsit after writing the word, or the error is corrected during typing. In the former case, central executive control is involved, while in the latter case, executive control is implemented on the periphery without central involvement. To test this hypothesis,two experiments should be conducted: copying and free-forming sentences. In sentence formulation, executive control of error correction is mainly implemented in the central departments, while in copying, it is implemented in the periphery. Thiscould be due to the fact that sentence formulation involves other mental processes besides typing motor control, which results in a greater cognitive load. Spectral analysis of EEG data could also be used to capture executive control.

Cognitive Flexibility

The study of motor circuits involved in word and sentence typing can provide insights into cognitive flexibility, which refers to the ability to switch between activation and inhibition during typing, as noted by [118]. One way to study switching processes is to use LRP, which allows predicting the sequence of keystrokes during typing. The amplitude of LRP can also indicate the alternation of inhibition and activation processes during typing, thereby illustratingthe process of switching between right or left-hand signals, as discussed by van derMeer and Van der Weel (2017) [116].

Another way to study switching processes in typing is by examining word or sentence formulation from pictures. This is because typing words from certain images (e.g., an apple) requires switching between different modalities, and thus, switching processes between verbal and nonverbal processes can be observed by comparing EEG data when copying a word and when typing from a picture, as notedby Pinet and Nozari (2020) [92].

Working Memory

When studying word or sentence typing from memory, such as in a modifiedn-back task, researchers can observe not only the number of words recalled but alsothe psychophysiology of working and semantic memory by comparing spectral power during copying and recalling sentences, as noted by Miller, Lundqvist, and Bastos (2018) [80].

Additionally, studies on the formulation of sentences from memory can reflectthe functioning of working memory. The inner loop only processes the information transmitted to typing, while the outer loop has more complete information about the sentence as a whole, but does not store information about typing details, such as which hand is used or the placement of letters on the keyboard, as discussed by Logan and Crump (2011) [72]. This reflects the information storage and processing process in working memory. By presenting a word to a participant and asking themto formulate a sentence using that word, researchers can trace the neural activation and inhibition processes in the typing process, and analyze the neurophysiology of working memory processes as a function of the need to remember the stimulus word,as suggested by Miller, Lundqvist, and Bastos (2018) [80]. This is particularly relevant when the word is not presented on the screen during the task, requiring theparticipant to engage working memory, as noted by Baus et al. (2005) [15].

Chapter 2: Research Methods and Results

The study was supported by RFBR grant No. 20-313-90046 \ 20 dated 13.09.2020, supervisor: E. L. Grigorenko.

The **subject** of this study is executive functions: processes of working memory functioning, executive control, as well as processes of switching and inhibition.

The **object** of the research are neurophysiological markers of executivefunctions during typing.

The **aim** of this study is to determine neurophysiological correlates of executive functions during typing.

In order to realize the aim, we set the following **tasks**:

1. Determine which of the behavioral indicators of executive functions in the conducted techniques show the highest correlation between each other.
2. Determine which of the behavioral characteristics of typing can act as an additional factor in the models of executive functions in typing.
3. Evaluate the level of interaction of typing behavioral characteristics with the level of development of executive functions.
4. Evaluate spectral characteristics of neuronal activation during execution of a print task for recalling text, depending on the level of development of working memory, inhibition and switching processes.
5. To evaluate the spectral characteristics of electrical activity in the process of sentence formulation depending on the level of development of executive functions.
6. To compare spectral characteristics of electrical activity during copying and formulation of sentences.

Based on the above, we can formulate the following research **hypotheses**:

There is a model that can describe the variance of activation power of alpha, beta and theta rhythms during typing on the computer throughthe level of executive functions, working memory and inhibitory processes, measured by the BRIEF method.

Let us also determine the operational hypotheses, based on those described above.

1. There will be a significant correlation between the results of the BRIEF-2 and UNIT techniques, which measure the level of development of the corresponding executive functions.

2. There will be a statistically significant contribution of the level of executive function development to behavioral performance in typing.

3. The model that best describes the variance of activation of alpha, beta, andtheta rhythm power during typing includes predictors such as memory, working memory, inhibitory process severity, and level of executive control development asmeasured by psychological techniques.

3.1 There will be a statistically significant contribution of measures ofexecutive function development to prefrontal and motor cortex activation when typing a recall sentence.

3.2 There will be observed a statistically significant contribution of the indicators of the development of executive functions in the activation of the prefrontal and motor cortex when typing a sentence formulated from a picture.

4. There will be statistically significant differences in high-frequency rhythms between the processes of copying and sentence formulation.

To summarize, we have proposed operational hypotheses that describe the relationship between the neurophysiological patterns in copying and formulating a sentence, and the executive functions that are involved in this process.

2.1 Description of the study

The study sample consisted of 49 people (M (SD)=18.64 (0.74)), including30 women (M (SD)=18.54(0.74)), 19 men (M(SD)=18.94 (0.73)). Participants were recruited on the Internet, through the advertisements in communities in the social network «Vkontakte». Limitations of the sample were determined by age (16-18 years), typing skills (speed of at least 150 characters per minute, typing accuracy of at least 97%), and the absence of traumatic brain injuries and other neurological disorders. The typing test was conducted online, and the results weresent to the recruiter in the form of certificates of passing the test. Before startingthe study, all participants signed an informed consent for participation (Appendix 1), which was approved by the Ethics Committee of the Institute of Psychology of the Russian Academy of Sciences (Appendix 2). After the study, each of the participants was givena reward equivalent to 1,000 rubles.

The study was conducted in the Laboratory of Interdisciplinary Studies of Human Development at St. Petersburg State University. The procedure includedtwo blocks: behavioral and psychophysiological. The behavioral block includedmethods measuring the level of development of the participant's intellect and executive functions, and the psychophysiological block included a psychophysiological experiment and a questionnaire of the leading hand (Figure1). The entire study took about 4 hours, with a break of at least 1 hour between parts of the study.

The behavioral data collection procedure began with acquaintance of the participant with the techniques to be performed. Next, the participant completed the BRIEF-2 self-completion questionnaire and the UNIT-2 technique. The behavioral block took no more than 2 hours.

The neurophysiological data collection procedure began with familiarizing the participant with the study protocol. The goals and objectives of this stage of the study were briefly explained. To optimize the recording procedure, the participant's head volume for EEG cap selection was measured in advance, and the electrode cap was prepared before the study began. The psychophysiological part was performed in an isolated room. The process of connecting the electrodes took 30 to 60 minutes and was performed by applying a hypoallergenic electrolyte gel to the scalp, to increase conductivity and decrease resistance. After the electrodes were placed, the participant was asked to turn off mobile devices or put them into flight mode, and to make as few movements as possible. The psychophysiological block took about 2 hours.

The study evaluated the psychophysiological indicators of computer typing and their correlation with indicators of executive functions.

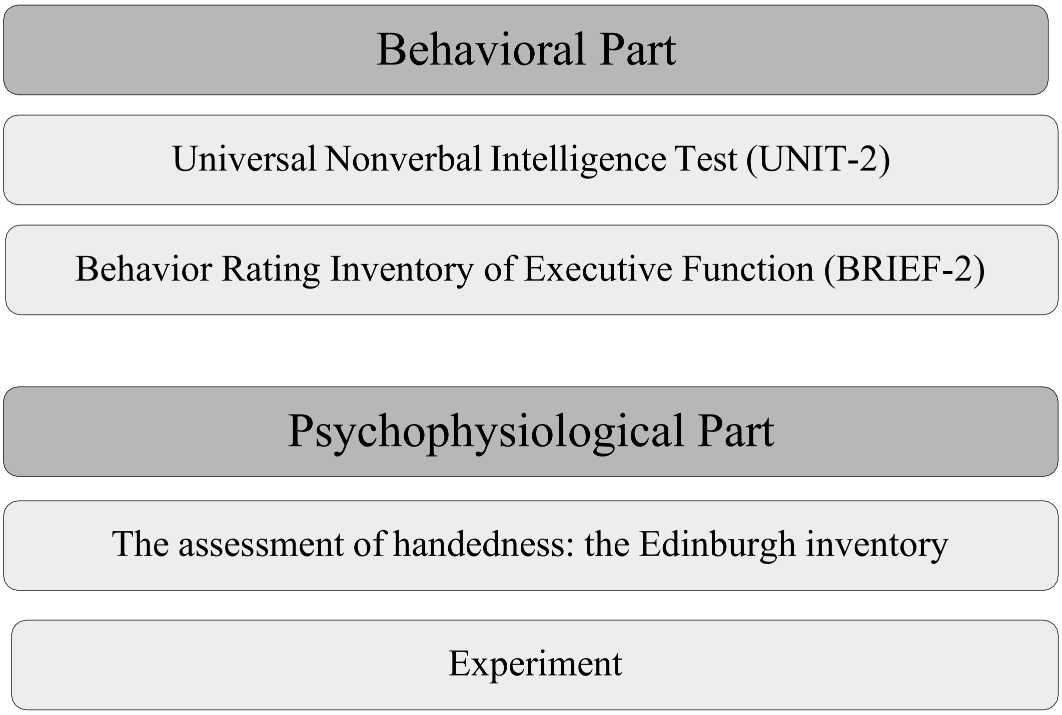

Figure 1 - Research structure

2.2. Behavioral methods

2.2.1. Research of executive functions. BRIEF–2

Since the main hypothesis of the study is the relationship between executive functions and the typing, an important factor is to determine the level of developmentof executive functions. In order to achieve the greatest reliability two methods werechosen. The respondent's level of executive function development was assessed using the Behavior Rating Inventory of Executive Function (BRIEF-2; Gioia,Isquith, Guy, & Kenworthy, 2000) and some subtests of the Universal Nonverbal Intelligence Test (UNIT-2, Universal Nonverbal Intelligence Test, Second Edition, Bruce A. Bracken, R. Steve McCallum, 2016).

Currently, there is a large amount of research aimed at studying executive functions, as they play an important role in emotional, cognitive, and behavioral development [34]. One widely used questionnaire to examine executive function is the BRIEF-2[31]. This questionnaire is used inschools and health care settings, as well as in various studies involving children, adolescents, and adults [99]. The BRIEF-2 is used to examine individuals without behavioral difficulties as well as those with developmental, somatic, neurological, and psychiatric disorders. For the purposes of this study, we used a self-report form (BRIEF-2: Gioia et al., 2009).

The BRIEF-2 structure is based on the theory of hierarchical organization of executive functions [10]. According to this theory, the management ofcomplex behavior is based on the regulation of basic processes. That is why the BRIEF-2 model can be viewed as a hierarchical structure in which scales form higher-order indices. The second edition of the methodology (self-questionnaire form) includes seven scales: Inhibit, Self-Monitor, Shift, Emotional Control, Working Memory, Plan/Organize, Task-Monitor. These scales are organized into three comprehensive indexes reflecting executive functions: "Behavior Regulation Index", "Emotional Recognition Index", and "Cognitive Regulation Index". Their combination is illustrated by the "General

Index of Executive Functions" [50].

The Inhibition scale assesses the level of inhibitory control, i.e., the ability to consciously not respond to stimuli. This scale also includes the ability to stop one's own actions at certain times. The Self-regulation scale assesses the contribution of the individual's behavior to the influence of the people and phenomena around him or her. Self-regulation is presented as the ability to observe and evaluate one's own behavior, assess one's own weaknesses and strengths, and evaluate one's effectiveness in solving problems. The Transference Scale measures the ability to beflexible in problem solving, shifting attention, and changing focus. The Emotional Regulation Scale measures control of mood changes, impulsivity, and lability of emotional state, as well as captures the frequency of overreactions to situational stimuli. The Task Monitoring Scale assesses success in problem solving and task completion. The Working Memory Scale assesses the ability to regulate the thoughtprocess, as exemplified by task tracking, as well as the ability to maintain concentration. The Planning/Organization Scale relates to the ability to anticipate future events and organize information. Behavior Regulation Index - represents the ability to effectively monitor and regulate behavior. The Emotional Regulation Index reflects the effectiveness of monitoring and regulating the emotional state. Correspondingly, the Cognitive Regulation Index assesses the effective regulation of cognitive processes. The Global Executive Function Index illustrates an overall measure of difficulties with executive functions.

Although the BRIEF-2 demonstrates high diagnostic validity, some studies have pointed to inconsistencies between the results of the technique and behavioraltests. According to the literature, executive functions can be divided into «Cold» and «Hot». «Cold» can include the cognitive part of executive functions, i.e., working memory, executive control, and organizational skills. Whereas "Hot" can include emotional regulation abilities [106]. The researchers suggest that different manifestations of IF are better assessed by different methods, because laboratory tests may be insensitive to some segments towhich BRIEF-2 is sensitive, and vice versa. In this regard, another technique measuring executive functions was chosen.

2.2.2 Study of Executive Functions and Intellectual Development.UNIT-2

Also, to determine the level of development of working memory, spatial and abstract thinking and intelligence we chose the Universal Nonverbal Intelligence Test, UNIT-2 (Universal Nonverbal Intelligence Test, Second Edition, Bruce A. Bracken, R. Steve McCallum, 2016). The methodology has a hierarchical structure. The participant performs six subtests, each focusing on a specific cognitive ability: symbolic, spatial and working memory, symbolic and non-symbolic counting, and analogy thinking. These subtests form three domains: Memory, Quantitative Thinking, and Reasoning. All scales summarize a measure of a participant's intelligence. It is worth noting that this methodology also includes a brief intelligence scale, which is calculated using subtests of non-symbolic counting and analogies. Let us dwell in a little more detail on each of the subtests.

Symbolic Memory

The Symbolic Memory subtest uses a sequence of universal symbols ("child," "girl," "boy," "woman," and "man") in two colors (green and black). Participants (ages 8-21) are presented with a sequence of figures for 5 seconds, after which the demonstration stops. Participants need to reproduce the sequence of figures with answer cards.

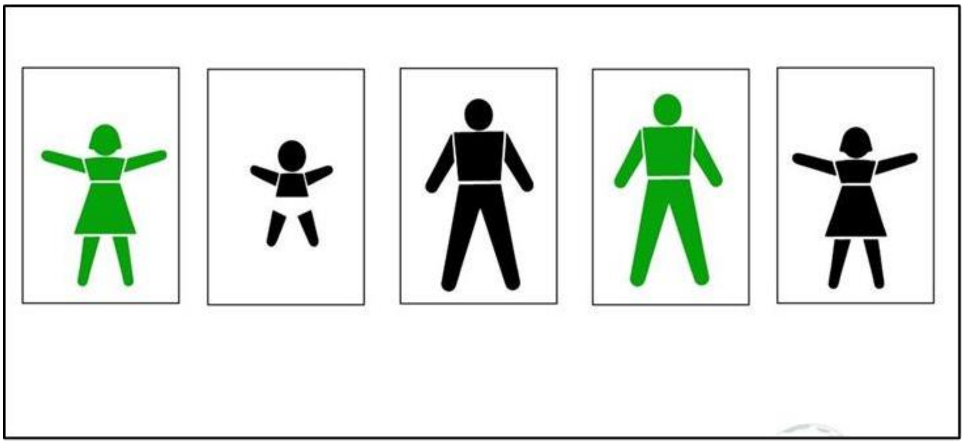

Figure 2 – Example of the stimulus material of the subtitle «Symbolic Memory» of the UNIT-2 method

The task assesses the ability to pay attention to details and to distinguish important information from insignificant information; to organize and remember complex information; to organize information meaningfully; to understand and solve multi-step mathematical problems; and to ignore extraneous, competing information during problem solving. It can be assumed that the task assesses working memory.

Non-Symbolic Account

The Non-Symbolic Account subtest uses a set of black and white dominoes with different numerical values creating a numerical sequence, identity, analogy, or mathematical problem. The participant must select the one that best fits the problemfrom the options provided.

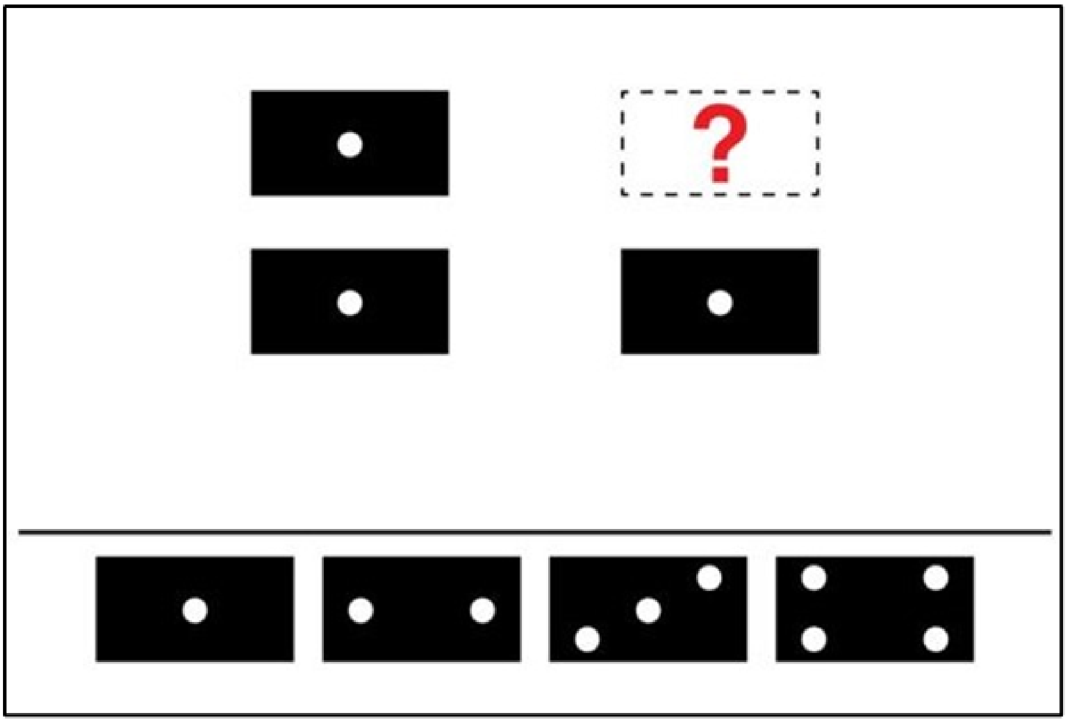

Figure 3 – Example of the stimulus material of the subtitle «Non-Symbolic Account» of the UNIT-2 method

The task assesses the ability to understand and solve abstract problems using symbols; to determine relationships between numbers; understand relationships represented by numbers; analyze and classify numerical (quantitative) information; generalize learned principles to solve new problems (e.g., apply already learned rulesto new examples or types of problems).

Analogy

Each item on the Analogies subtest presents an incomplete conceptual or geometric analogy represented in the form of a matrix. After three consecutive incorrect answers, the technique is terminated. The task assesses the ability to understand and solve practical, situational problems; to determine the relationship between cause and effect; to give rational arguments based on consistent logic; to generalize learned principles to solve new problems; and to systematically assimilateand use rules.

Spatial Memory

The stimulus material for the subtest is a matrix (1 × 2, 2 × 2, 3 × 3, or 4 × 4)with green and black chips randomly placed on it. You have 5 seconds to memorizethe location of the objects, and then reproduce it exactly on the answer sheet.

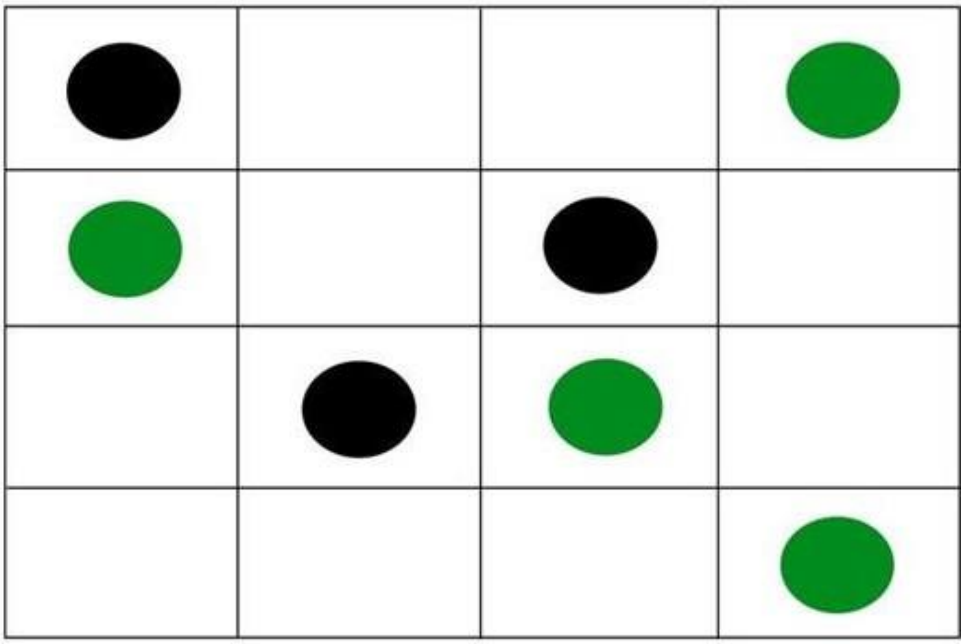

Figure 4 – Example of the stimulus material of the subtitle «SpatialMemory» of the UNIT-2 method

The task assesses the ability to see the situation as a whole; to pay attention to, process, and remember visual details, the essence of the information rather than the sequence in which it was presented; to concentrate on the problem until the problem is understood; and the ability to note minor changes in the environment.

Numerical series

Each item on the Numerical Series subtest is a set of numbers or mathematical symbols from which to create a perceptual pair or to continue a quantitative series. The task assesses the ability to understand and solve mathematical problems; identify relationships between numbers; understand relationships represented by numbers; analyze number systems; generalize learned principles to solve newproblems; and systematically use learned rules. Unlike the nonnumeracy tasks, thisunit assesses knowledge of mathematical rules and the ability to apply them to newsituations.

Cube Design

Stimulus material for the subtest includes 9 two-color dice from which you must assemble the designs represented in the image. The assignment is timed. The task assesses the ability to break down a problem into discrete pieces and solve them consistently; persistence in solving complex problems; responsiveness to completing tasks within a limited time frame; flexibility in evaluating and modifying solution strategies; and the ability to navigate one's surroundings.

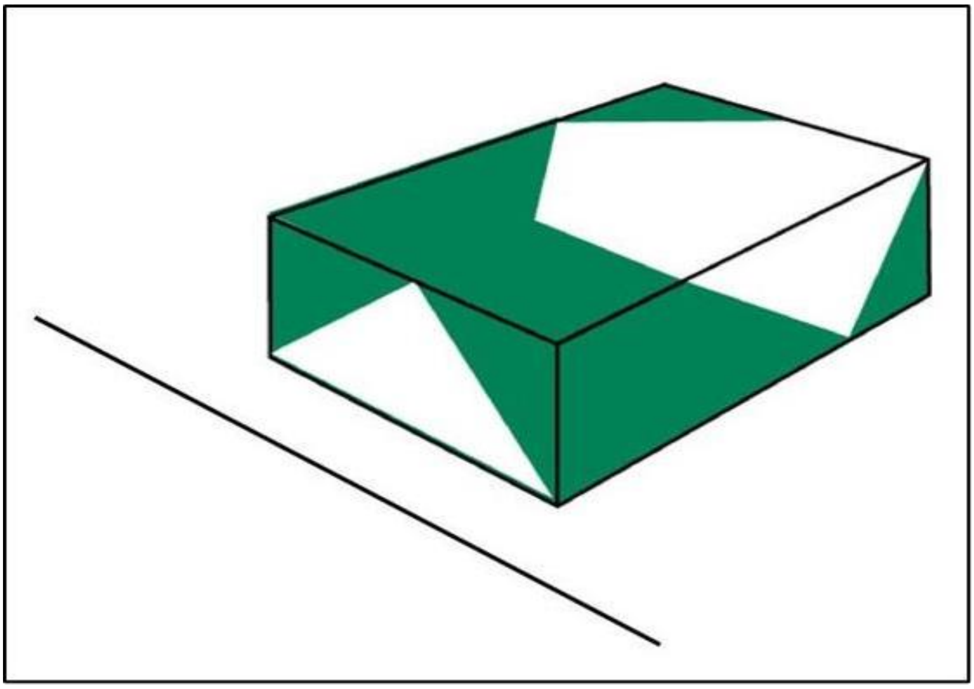

Figure 5 – Example of the stimulus material of the subtitle «Cube Design» of the UNIT-2 method

This methodology is non-verbal, so there are no obstacles in using it on the Russian sample. The technique includes all the domains of interest, and also allowsa complete assessment of the participant's intelligence.

2.3. Psychophysiological Methods

To determine the psychophysiological patterns of written speech, a psychophysiological experiment was developed in the software package Presentation (Neurobehavioral Systems, Inc.). This program meets the requirements necessary to conduct a psychophysiological experiment. It provides the use of any stimulus material, has the ability to connect a portable keyboard or other input device. Free environment for writing code enables any manipulation necessary for an experiment or series of experiments.

EEG recording was provided using BrainVision Recorder software (BrainProducts, Inc.) Total resistance across all leads was kept below 25 kΩ. The setup included the following equipment: an actiCHamp EEG amplifier (BrainProducts, Inc.) with 128 active Ag/AgCl electrodes; a laptop with Presentation stimulus presentation software package installed (Neurobehavioral Systems, Inc.); alaptop with BrainVision Recorder software package installed (BrainProducts, Inc.).Correction of label timing on the EEG recordings using the StimTrak device(BrainProducts, Inc.) was performed after the material was recorded.

Also, because predicting the typing of subsequent letters is more cognitively challenging in free speech, the second part of our study examined the relationship between the level of executive function development and the spectral load during typing. Accordingly, the experiment consisted of several blocks to determine a complete writing model. Also, two groups were introduced to better understand theprinciple of executive functions: a control group and an experimental group. In the control group, participants performed tasks without engaging working memory, andin the experimental group, tasks were performed with recall. Let us consider each ofthe blocks in more detail.

Table 1 - Description of the experimental block of the psychophysiological experiment

Block	**Control Group**	**Experimental Group**
Coping Sentences	Typing by memory	Typing by memory
Formulation Sentences	Typing by observing the stimulus materials	Typing by memory

2.3.1. Coping Sentences

The aim of the first block of the experiment was to study the neurophysiological processes in working memory and executive control involvedin typing, as well as the amount of working memory during typing. In this blockof the experiment, copying sentences was presented. We used 13 sentences that included all letters of the alphabet (Appendix 3). The sentences numbered from7 to 14 words of varying degrees of lexical complexity. The sentences were grammatically correct and semantically meaningless. The participant's task was to memorize the maximum number of words in the sentences during the presentation time (5000 ms), after which the participant had to type the maximumnumber of memorized words.

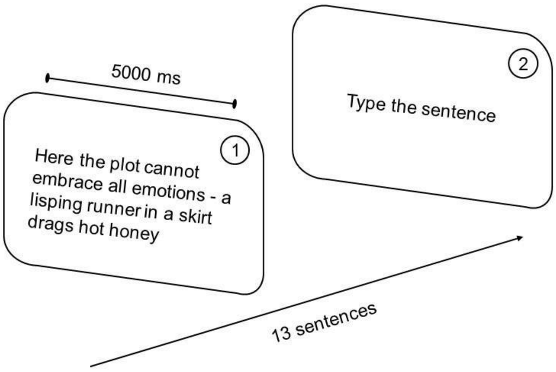

Figure 6 – Scheme of the «Copying Sentences» experiment

2.3.2 Formulating Sentences

The second block of this experiment was the formulation of sentences.Twenty-four images from the standardized Formulated Sentences Examiner's Manual (Clinical Evaluation of Language Fundamentals®-Fifth Edition, CELF®-5;Elisabeth H. Wiig, Eleanor Semel & Wayne A. Secord, 2013) were used to control the experimental conditions. The respondent was presented with an image (Appendix 5) with a word (Appendix 4) written over it. The respondent's task was to describe the situation from the picture using the word. Different groups varied the condition of the typing in the experiment. The control group of respondents typed sentences while observing the image, and the experimental group first memorized the image and the word for 5 seconds and then typed it. The experiment is aimed at studying the respondent's free speech. As well as to reveal psychophysiological patterns of working memory.

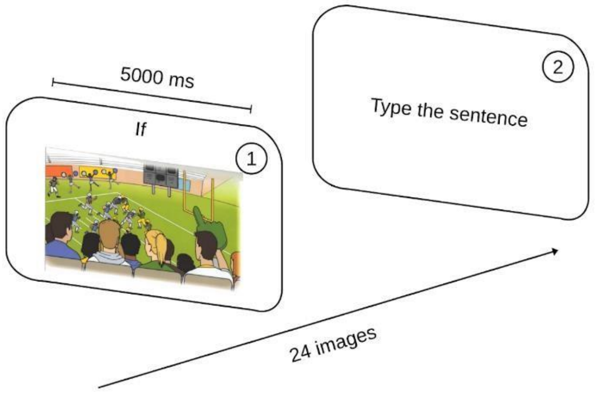

Figure 7 – Scheme of the «Formulation Sentences» experiment

To determine the respondent's leading hand, the assessment and analysis of handedness: the Edinburgh inventory (Oldfield, 1971) was used.

Due to the pandemic coronavirus infection, factors that would ensure an appropriate level of safety (e.g., protective suits, masks, gloves, and minimization of contact with the experimental participant) were taken into account in the protocolfor the preparation and conduct of the EEG study. Changes were made according tothe protocol for reducing COVID-19 transmission risk in EEG research developed by Aaron M. Simmons and Steven J. Luck Center for Mind & Brain, University of California Davis.

2.4. Data Preprocessing.

The data were preprocessed in Brain Vision Analyser software (BrainProducts, Inc.) The sampling rate was lowered to 500 Hz, the data were filtered (lower frequency 0.1 Hz, upper frequency 70 Hz). The recording quality of the channels was pre-checked with automatic software processing, and if more than30% of the recorded data on a channel was noisy (showed artifacts), the channel wasdeleted. After automatic checking, the channels were checked again - each recordingwas reviewed manually. Channels that showed artifacts in more than 30% of the recordings, but were not automatically detected, were also deleted. The next step was to remove ocular activity from the data using the ICA (Independent Component Analysis) algorithm [1]. Components of horizontal eye movements (right and left eye movements) were calculated by analyzing data from electrodes FT9 and FT10, components of vertical eye movements (blinking) were calculated from electrode Fp1 or electrode Fp2. In case data from both electrodes were unsatisfactory, the most pronounced vertical eye movements (e.g. AF8) was demonstrated as the reference electrode. Also, a step change of the reference electrode was applied to the data. Theaverage value of all recorded electrodes was considered as the reference electrode.

After this step, an automated check of the noisiness of the EEG channel recordings was performed again. If electrodes were found that exhibited noisiness by more than 15%, the preprocessing process was repeated from the electrode removal step. Otherwise, all removed electrodes were restored using topographic interpolation. Further processing of the recordings was performed automatically for the entire dataset and included the following steps. The recordings were preliminarily segmented according to conditions, depending on the type of paradigm. For paradigms that involved spectral analysis, the segments were divided into 4-second chunks with a 50%

overlap. This was followed by removal of segments that contained artifacts, with an amplitude sweep of ± 110 mV. Trends were then removed over an intervalof 2-4000 ms, and the segments were averaged by stimulus type with standard deviation calculation. After the preprocessing was completed, a Fourier analysis wasperformed, with separation into the following spectral bands: delta (1.5-6 Hz), theta(6.5-8 Hz), alpha-1 (8.5-10 Hz), alpha-2: (10.5-12 Hz), beta-1 (12.5-18 Hz), beta-2 (18.5-21 Hz), beta-3 (21.5-30 Hz), gamma (30-44 Hz) [62].

2.5 Mathematical and statistical methods of data processing.

All mathematical and statistical data processing was performed using the R-Studio software (version 4.1.1). The following libraries were used in the analysis: car, ggplot2, tidyverse, psych, dplyr, data.table, Hmisc, GGally, lme4, lmerTest. The following methods were used to analyze the results obtained:

1. Shapiro-Wilks criterion to determine the normality of the distribution of variables;
2. Pearson's $\chi 2$ test to determine sample homogeneity by gender and age;
3. T-Student's test for comparing scaled measures of executive function between groups;
4. Single factor analysis of variance (ANOVA) for comparison of intellectual development level between groups;
5. Correlation analysis to determine the relationship between scaled measures of techniques and print behavioral measures;
6. Cluster analysis to identify groups with different levels of executivefunction development.
7. Two-factor analysis of variance (ANOVA) to compare neuronal scores between the resulting clusters.
8. Construction of a regression model of neuronal activation depending onthe level of executive function development.

Chapter 3. Result

3.1 Descriptive Statistics

Participants showed a normal distribution in terms of intelligence (M(SD) = 109.73 (9.24)), however, the sample tended to perform better than the normotypic cutoff. Also, control (23 participants (14 w), M(SD) = 18.43(0.73), IQ: M(SD) = 107.04 (9.86)) and experimental groups (26 participants (16 w), M(SD) = 18.92(0.69), IQ: M(SD) = 112.40 (7.46)) were randomly formed from participants, differing in type of experiment. There were no statistically significant differences inage ($\chi2$ (3) = 6.35, $p >0.05$) or gender ($\chi2$ (13) = 12.874, $p >0.05$) between groups. No differences in intellectual development between participants were found by single-factor analysis of variance (ANOVA) (F (1,47) = 0.45, $p>0.05$).

All UNIT-2 and BRIEF-2 scores were tested for normality and homogeneity beforehand. As a result of the analysis, only the Monitoring and General Emotional Index scales did not pass the normality test, but since these scales are not used in the analysis, but further analysis is valid. We plan to use the scaled scores on the BRIEF-2 scales: Inhibition, Transference, Working Memory; and the UNIT-2 Memory score as independent variables in the analysis.

The Shapiro-Wilkes test showed a normal distribution in the UNIT techniqueon the scales of Memory (W = 0.97, p = 0.17), Thinking (W = 0.98, p = 0.40), and Intelligence (0.96, p = 0.06). Also according to the BRIEF technique, the scales of interest of Working Memory (W = 0.98, p = 0.38), Inhibition (W = 0.97, p = 0.25), Switching (W = 0.98, p = 0.55) showed a normal distribution.

These results may indicate that the sample is fairly evenly distributed in termsof age, intelligence, and results of techniques on executive functions. Which allowsus to conclude that the indicators of comparison of averages and variance obtained in the further analysis can be used, and that this sample is representative. Since Student's test showed no statistically significant differences between the averages of the groups, we can assume that the obtained groups are homogeneous according to these indicators, which we will need for further analysis.

3.2. Results of Correlation Analysis of Behavioral Methods

All variables were pre-checked for normality and were scored. Allvariables of interest were normally distributed. The results of the behavioral analysis showed the following correlations. There was a high correlationbetween decision indices and intelligence (r=0.67, p < 0.01). In this study, we do not focus on decision-making processes, so this variable was not included asan independent variable in the analysis. We also observe average correlations between switching and inhibition processes (r=0.48, p < 0.01), and switching and working memory (r=0.57, p<0.01), which we regard as indicators of executive control and working memory, respectively. The results obtained illustrate a high correlation for the indicators of interest within the techniques, whereas this trend is not observed between techniques. Accordingly, we can assume that these techniques cover different domains of executive functions. For example, the respondent's visual working memory modality is much betterdeveloped than the spatial one (Chai et al., 2018), and therefore the literature recommends giving multiple techniques on executive functions to ensure morecomprehensive coverage [12].

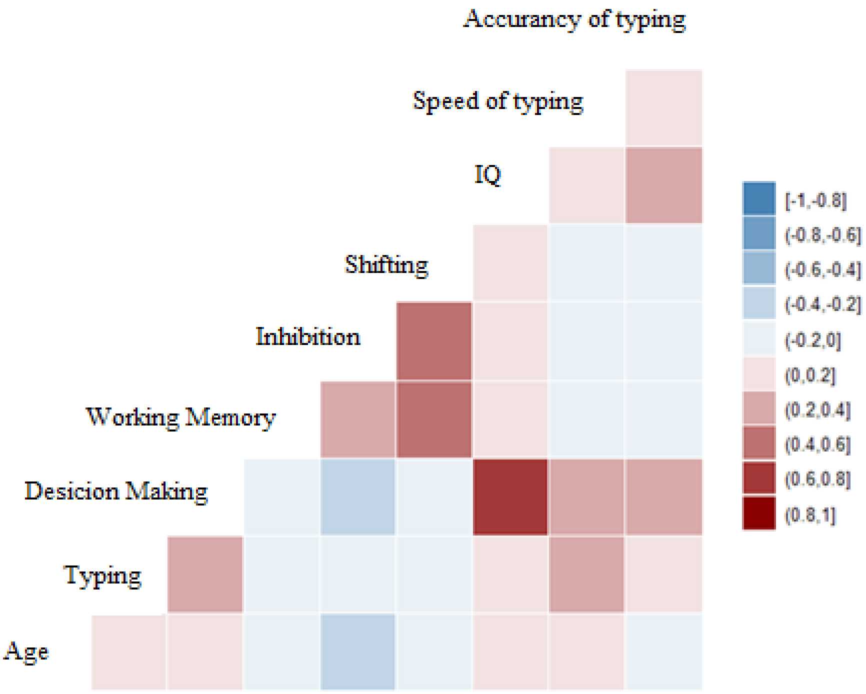

Figure 8 – Results of correlation analysis of UNIT-2 and BRIEF-2methods and behavioral indicators of typing.

Notes. This graph shows the strength of the correlation between subtests illustrating indicators of development of executive functions according to various techniques and behavioral indicators of typing. The strength of the correlation is determined by color differentiation, from dark maroon (strong) to dark blue (weak).

It is also possible to note the differences in the results of the self- questionnaire and the methodology of real achievements. An important conclusion based on the results will be that future models will need to include several scaled indices, with adjustments for the respondent, as this will give greater accuracy in building the model.

3.3. Results of Behavioral Indicators in Typing on the Computer

To analyze the behavioral results of the EEG experiment, the ratio of thetotal number of correctly typed words to the total number of words was used. Using the obtained index (WR) as a dependent variable, a regression model was built with the IF indices as independent variables (Memory Index according tothe UNIT-2 method, Inhibition, Working Memory and Switching Indicesaccording to the BRIEF-2 method). According to the results of the behavioral analysis of the EEG experiment, the following results can be said (Table 1). There was a statistically significant contribution of the independent variable Inhibition Index (ANOVA III: F (1) = 6.74, p<.01, ɳ = 0.013 [CI:.01-.09].

The number of correctly typed words increases as the Inhibition Index increases. According to the theory of two feedback loops put forward by Loganand Crump (2011), in typing inhibitory (inhibitory) processes appear at the moment of typing each next letter, as they "inhibit" typing of all variants of subsequent letters (Pinet et. al., 2015). Accordingly, it can be assumed that themore active these processes are, the higher is the accuracy of the printed letter,because the inhibitory processes successfully cope with the task. Based on thisassumption, we can say that our results illustrate the fact that the higher the accuracy of writing, the better the inhibition skill of the respondent is developed. Separately, it should be noted that all the sentences presented to the participants were identical - that is, the difficulty of the task was the same, and, consequently, the accuracy score was quite individual.

Table 2 – LRM results: Contributions of EF indexes to behavioral results of coping sentence.

Predictors	Estimates	CI	p
(Intercept)	0.58	0.54 – 0.61	<0.001
Memory	0.02	-0.02 – 0.05	0.353
Inhibit	0.05	**0.01 – 0.09**	**0.013**
WM	0.01	-0.04 – 0.05	0.769
Shift	-0.03	-0.08 – 0.01	0.151
Observations	48		
R2 / R2 adjusted	0.149 / 0.070		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Braking Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2.

3.4. Results of cluster analysis

Due to the fact that the results of the correlation analysis show correlation onthe IF, it was decided to divide the participants into clusters, for further analysis, inorder to level out the correlation effects.

The first cluster (n=12) included participants who demonstrated low levels of Working Memory (M=-1.14, SD=0.61) and lower scores on Inhibition (M=-0.62, SD=0.8) and Switching (M=-1.19, SD=0.53) factors. In turn, Memory scores (M=0.47, SD=0.92), according to the UNIT-2 methodology, were quite high in theseparticipants.

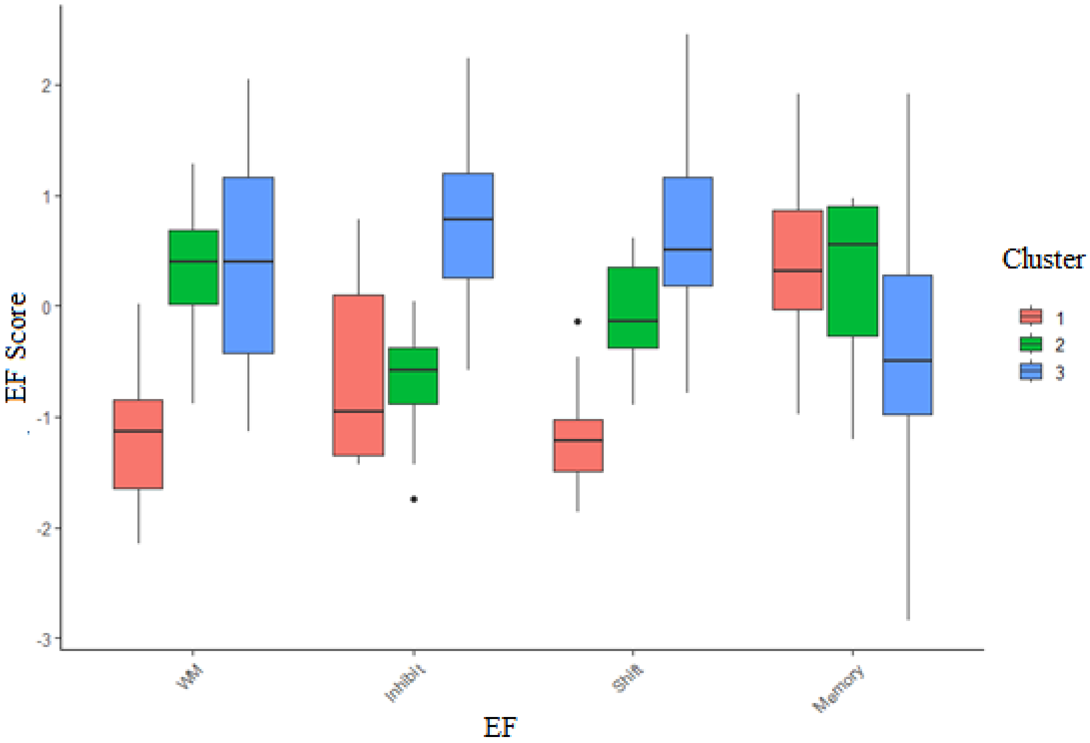

Figure 9 - Distribution of participants into clusters according to IF development

Notes: Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2

Clusters; 1 - Level of executive function development below average, 2 - Level of executive function development on the border of average, 3 - Level of executive function development above average.

The second cluster (n=14) included participants with high scores on Working Memory (M=7.50, SD=4.18) and Total Memory (M=0.25, SD=0.76), while Inhibition (M=-0.70, SD=0.50) and Switching (M=-0.08, SD=0.49) were below the sample average.

The third cluster (n=23) demonstrated high scores on Inhibition (M=0.75, SD=0.75), Switching (M=0.67, SD=0.80), and Working Memory (M=0.38, SD=0.92), and high variance on Memory (M=-0.40, SD=1.04), with a mean value just below the mean.

The resulting clusters may demonstrate the following groups:

1. Level of development of executive functions below average.
2. The level of development of executive functions on the border of theaverage.
3. The level of development of executive functions is above average.

3.5. Results of the Copying Sentence Experiment

We preliminarily selected only the data falling in the theta, alpha, and beta ranges from the entire EEG data set. Spectral values exceeding 50 μV2 were excluded from the analysis. Further, values exceeding two standard deviations for the behavioral indices of interest (the UNIT-2 Memory Index, the BRIEF-2 Inhibition, Working Memory, and Switching Indices) were removed from thesample. Only those indices showing a correlation above 40% were included in further regression analysis.

Fourier transform results in the prefrontal, frontal, central, and central-parietal regions were analyzed. LMM (Linear mixed model) were constructed on the remaining data set. Spectral power was considered as the dependent variable, and various indexes of the IF, as well as channels and percentage of correctly typed words (WR) were considered as independent variables.

A significant effect of executive function indices on alpha rhythm power was found (Table 3) (F (18,1563) = 59.86, p < 0.001).

Table 3 - Contribution of EF indicators to the power density of EEG rhythm during sentence copying

	Alfa Power Density		
Predictors	*β*	*CI*	*P*
(Intercept)	-0.56	-0.73 – -0.39	**<0.001**
WM	-0.16	-0.20 – -0.11	**<0.001**
Shift	0.08	0.04 – 0.12	**<0.001**
Inhibit	0.06	0.02 – 0.10	**0.008**
WR	0.05	-0.20 – 0.30	0.702
Channel [C2]	0.20	0.07 – 0.33	**0.003**
Channel [C3]	-0.26	-0.39 – -0.13	**<0.001**
Channel [C4]	-0.17	-0.30 – -0.04	**0.012**
Channel [Cz]	-0.07	-0.20 – 0.06	0.310
Channel [FC1]	0.05	-0.08 – 0.18	0.470
Channel [FC2]	0.14	0.01 – 0.27	**0.034**
Channel [FC3]	-0.04	-0.17 – 0.09	0.555
Channel [FC4]	0.77	0.64 – 0.90	**<0.001**
Channel [FCz]	-0.29	-0.42 – -0.16	**<0.001**
Channel [Fz]	0.58	0.45 – 0.71	**<0.001**
WM × Shift	-0.07	-0.11 – -0.03	**<0.001**
WM × Inhibit	0.48	0.43 – 0.53	**<0.001**
Shift × Inhibit	-0.52	-0.57 – -0.48	**<0.001**
(WM × Shift) × Inhibit	0.05	0.02 – 0.09	**0.005**
Observations	1563		
R2 / R2 adjusted	0.411 / 0.404		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - WorkingMemory Index, BRIEF-2; Shift - Shift Index, BRIEF-2. Statistically significant values are shown in bold.

A significant effect of executive function indices on neuronal activity in the beta rhythm was found (Table 4) (F (18.8838) = 256.4, p < 0.001).

Table 4 - Contribution of EF indicators to the power of the EEG beta rhythm during sentence copying

	Beta Power Density		
Predictor	*β*	*CI*	*p*
(Intercept)	-1.28	-1.35 – -1.20	**<0.001**
Inhibit	0.05	0.03 – 0.07	**<0.001**
WM	-0.11	-0.13 – -0.09	**<0.001**
Shift	0.04	0.03 – 0.06	**<0.001**
WR	-0.20	-0.31 – -0.09	**<0.001**
Channel [C2]	0.19	0.13 – 0.24	**<0.001**
Channel [C3]	-0.18	-0.24 – -0.13	**<0.001**
Channel [C4]	-0.14	-0.20 – -0.08	**<0.001**
Channel [Cz]	0.09	0.03 – 0.14	**0.002**
Channel [FC1]	0.25	0.19 – 0.31	**<0.001**
Channel [FC2]	0.27	0.21 – 0.33	**<0.001**
Channel [FC3]	0.09	0.03 – 0.14	**0.002**
Channel [FC4]	0.66	0.61 – 0.72	**<0.001**
Channel [FCz]	-0.14	-0.20 – -0.09	**<0.001**
Channel [Fz]	0.78	0.72 – 0.84	**<0.001**
Inhibit × WM	0.37	0.34 – 0.39	**<0.001**
Inhibit × Shift	-0.45	-0.47 – -0.43	**<0.001**
WM × Shift	0.01	-0.00 – 0.03	0.159
(Inhibit × WM) × Shift	0.06	0.04 – 0.08	**<0.001**
Observations	8857		
R^2 / R^2 adjusted	0.346 / 0.344		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2. Statistically significant values are shown in bold.

A significant effect of executive function indices on neuronal activity in the beta rhythm was found (Table 5) (F (14, 1548) = 43.99, p < 0.001).

Table 5 - Contribution of the EF indicators to the power of theta rhythm EEG during sentence copying

		Theta Power Density	
Predictor	*β*	*CI*	*P*
(Intercept)	-0.03	-0.25 – 0.19	0.789
Memory	0.19	0.15 – 0.23	**<0.001**
Inhibit	0.14	0.10 – 0.18	**<0.001**
WR	0.13	-0.20 – 0.45	0.446
Channel [C2]	0.25	0.09 – 0.40	**0.002**
Channel [C3]	-0.38	-0.54 – -0.22	**<0.001**
Channel [C4]	-0.18	-0.34 – -0.03	**0.023**
Channel [Cz]	-0.21	-0.37 – -0.05	**0.009**
Channel [FC1]	-0.09	-0.25 – 0.06	0.248
Channel [FC2]	0.06	-0.09 – 0.22	0.426
Channel [FC3]	-0.12	-0.27 – 0.04	0.150
Channel [FC4]	0.87	0.71 – 1.03	**<0.001**
Channel [FCz]	-0.42	-0.58 – -0.27	**<0.001**
Channel [Fz]	0.52	0.37 – 0.68	**<0.001**
Memory × Inhibit	-0.09	-0.14 – -0.05	**<0.001**
Observations	1563		
R^2 / R^2 adjusted	0.285 / 0.278		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2. Statistically significant values are shown in bold.

After constructing the models, a two-factor analysis of variance was performed to determine the differences in neuronal activity in different spectral ranges between the different clusters (Figure 10).

A statistically significant interaction of the two predictors (rhythm and cluster) determining neurophysiological activity was found ((F (8, 51) = 7.60, $p < 0.001$). In turn, both predictors Cluster (F (2, 80) = 47.45, $p < 0.001$, ɳ2 = 0.02, and rhythm (F (4, 17119) = 5064, $p < 0.001$) showed statistically significant differences.

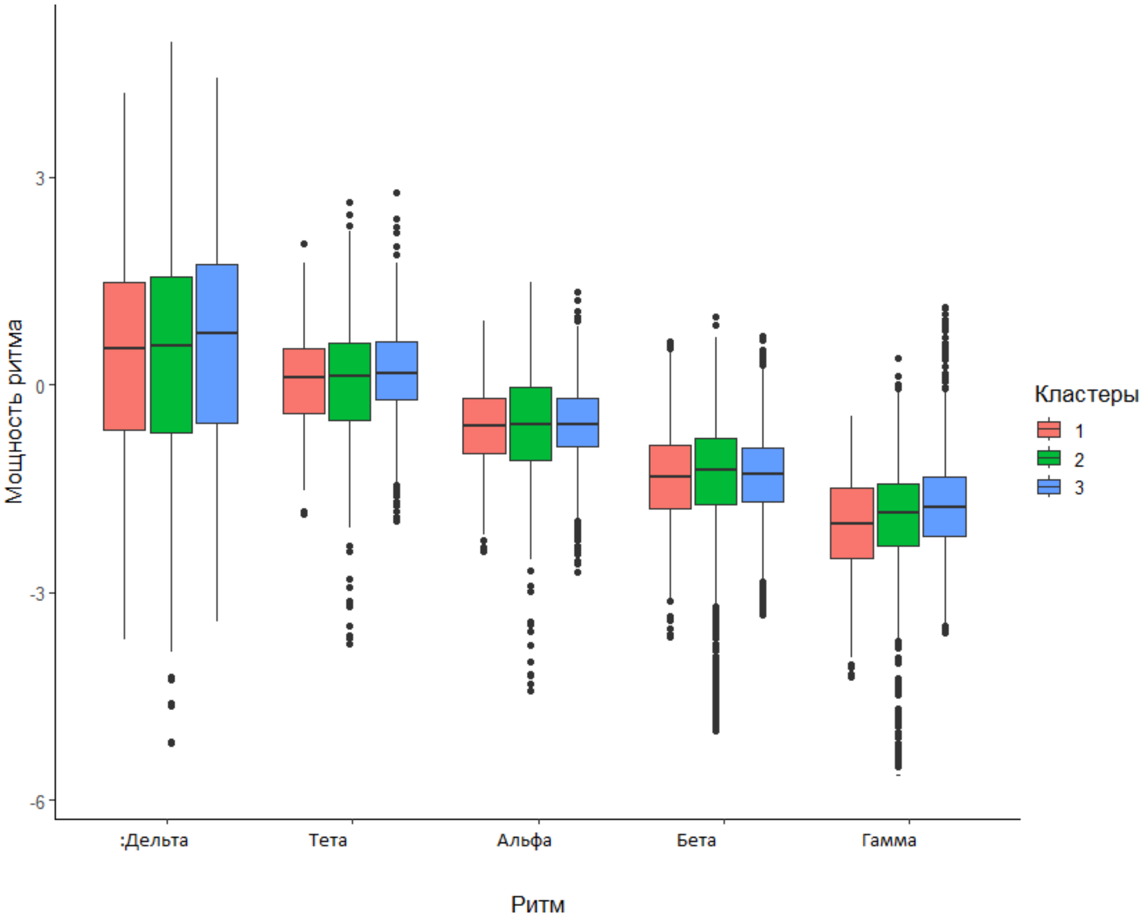

Figure 10 - Distribution of the power of rhythms in the process of copying sentences depending on the cluster

Notes: Clusters; 1 - Level of development of executive functions below average, 2 - Level of development of executive functions on the border of average, 3 - Level of development of executive functions above average.

According to Tukey's post-hoc criterion, no statistically significant differencewas shown in alpha beta and theta rhythms between the clusters. Which may indicatethat the trend of changing activation applies separately to each of their functions, rather than to the complex. Whereas in delta and gamma rhythms, we can observe statistically significant differences between the third and first clusters (Delta: diff =0.19, $p < 0.001$; Gamma: diff = 0.26, $p < 0.001$) and the third and second clusters (Delta: diff = 0.16, $p < 0.001$; Gamma: diff = 0.22, $p < .001$).

3.6. Results of the Formulation Sentences Experiment

We preliminarily selected only the data falling in the theta, alpha, and beta ranges from the entire EEG data set. Spectral values exceeding 50 μV^2 were excluded from the analysis. Further, values exceeding 2 standard deviations for the behavioral indices of interest (the UNIT-2 Memory Index, the BRIEF-2 Inhibition, Working Memory, and Switching Indices) were removed from the sample. Only those indices showing a correlation above 40% were included in further regression analysis.

Fourier transform results in the prefrontal, frontal, central, and central-parietal regions were analyzed. LMM (Linear mixed model) models were constructed on the remaining data set. Spectral power was considered as the dependent variable, and various indexes of the IF, as well as channels and the percentage of correctly typed words (WR) were considered as independent variables.

A significant ($F(18,1400) = 37.62$, $p < 0.001$) contribution of IF indices to alpha rhythm power was found (Table 6). Significant contributions of centralchannels C2, C3, FC2, FC4, FCz, and Fz were also shown to be predictors. Thus, we can observe that the greatest activation is observed in central and frontalchannels.

Table 6 - Contribution of EF indicators to EEG alpha rhythmpower during sentence formulation

Alfa Power Density

Predictors	*β*	*CI*	*P*
(Intercept)	0.95	0.73 – 1.18	**<0.001**
Memory	0.24	0.19 – 0.28	**<0.001**
Shift	-0.07	-0.11 – -0.03	**0.001**
Inhibit	0.14	0.10 – 0.18	**<0.001**
WR	-0.29	-0.63 – 0.05	0.096
Channel [C2]	0.20	0.06 – 0.34	**0.007**
Channel [C3]	-0.24	-0.38 – -0.10	**0.001**
Channel [C4]	-0.14	-0.28 – 0.00	0.055
Channel [Cz]	-0.05	-0.20 – 0.09	0.461
Channel [FC1]	0.10	-0.05 – 0.24	0.181
Channel [FC2]	0.19	0.05 – 0.34	**0.008**
Channel [FC3]	0.01	-0.13 – 0.16	0.857
Channel [FC4]	0.77	0.62 – 0.91	**<0.001**
Channel [FCz]	-0.24	-0.39 – -0.10	**0.001**
Channel [Fz]	0.69	0.55 – 0.83	**<0.001**
Memory × Shift	0.10	0.06 – 0.13	**<0.001**
Memory × Inhibit	-0.11	-0.16 – -0.06	**<0.001**
Shift × Inhibit	-0.14	-0.17 – -0.10	**<0.001**
(Memory × Shift) × Inhibit	-0.09	-0.13 – -0.06	**<0.001**
Observations	1419		
R2 / R2 adjusted	0,326 / 0,317		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2. Statistically significant values are shown in bold.

A significant (F(18, 8022) = 253.6, $p < 0.001$) contribution of the IF indices (Inhibition and Working Memory) to beta rhythm power was found (Table 7). Significant contributions of frontal and central channels were also shown.

Table 7 - Contribution of the IF indicators to the power of the EEG beta rhythm in the process of formulating sentences

		Beta Power Density	
Predictor	*β*	*CI*	*P*
(Intercept)	0.36	0.29 – 0.44	**<0.001**
Inhibit	0.06	0.04 – 0.08	**<0.001**
WM	-0.07	-0.09 – -0.05	**<0.001**
Shift	0.01	-0.01 – 0.03	0.324
WR	-0.57	-0.68 – -0.46	**<0.001**
Channel [C2]	0.21	0.15 – 0.27	**<0.001**
Channel [C3]	-0.18	-0.23 – -0.12	**<0.001**
Channel [C4]	-0.11	-0.16 – -0.05	**<0.001**
Channel [Cz]	0.06	0.00 – 0.12	**0.042**
Channel [FC1]	0.24	0.18 – 0.30	**<0.001**
Channel [FC2]	0.28	0.22 – 0.34	**<0.001**
Channel [FC3]	0.10	0.05 – 0.16	**<0.001**
Channel [FC4]	0.70	0.64 – 0.76	**<0.001**
Channel [FCz]	-0.15	-0.21 – -0.09	**<0.001**
Channel [Fz]	0.82	0.76 – 0.87	**<0.001**
Inhibit × WM	0.39	0.37 – 0.41	**<0.001**
Inhibit × Shift	-0.43	-0.45 – -0.41	**<0.001**
WM × Shift	-0.07	-0.09 – -0.05	**<0.001**
(Inhibit × WM) × Shift	0.06	0.04 – 0.07	**<0.001**
Observations	8041		
Marginal R2 / Conditional R2	0.363 / 0.361		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2. Statistically significant values are shown in bold.

A significant (F(14, 1404) = 37.72, p < 0.001) contribution of the IF indices (Inhibition and Memory) to the theta rhythm power was found (Table 8). A significant contribution of central channels was also shown.

Table 8 - Contribution of the IF indicators to the power of theta rhythm EEG during sentence formulation

	Theta Power Density		
Predictor	*β*	*CI*	*p*
(Intercept)	1.60	1.37 – 1.83	**<0.001**
Memory	0.15	0.11 – 0.19	**<0.001**
Inhibit	0.14	0.10 – 0.18	**<0.001**
WR	-0.28	-0.63 – 0.06	0.104
Channel [C2]	0.23	0.06 – 0.39	**0.006**
Channel [C3]	-0.33	-0.49 – -0.17	**<0.001**
Channel [C4]	-0.19	-0.35 – -0.03	**0.022**
Channel [Cz]	-0.17	-0.34 – -0.01	**0.034**
Channel [FC1]	-0.07	-0.23 – 0.10	0.418
Channel [FC2]	0.09	-0.07 – 0.25	0.291
Channel [FC3]	-0.10	-0.26 – 0.07	0.243
Channel [FC4]	0.84	0.67 – 1.00	**<0.001**
Channel [FCz]	-0.38	-0.54 – -0.22	**<0.001**
Channel [Fz]	0.62	0.46 – 0.78	**<0.001**
Memory × Inhibit	-0.04	-0.08 – -0.00	**0.048**
Observations	1419		
Marginal R2 / Conditional R2	0.273 / 0.266		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index,BRIEF-2; Shift - Shift Index, BRIEF-2. Statistically significant values are shown in bold.

After constructing the models, a two-factor analysis of variance was performed to determine the differences in neuronal activity in different spectral rhythms between the clusters.

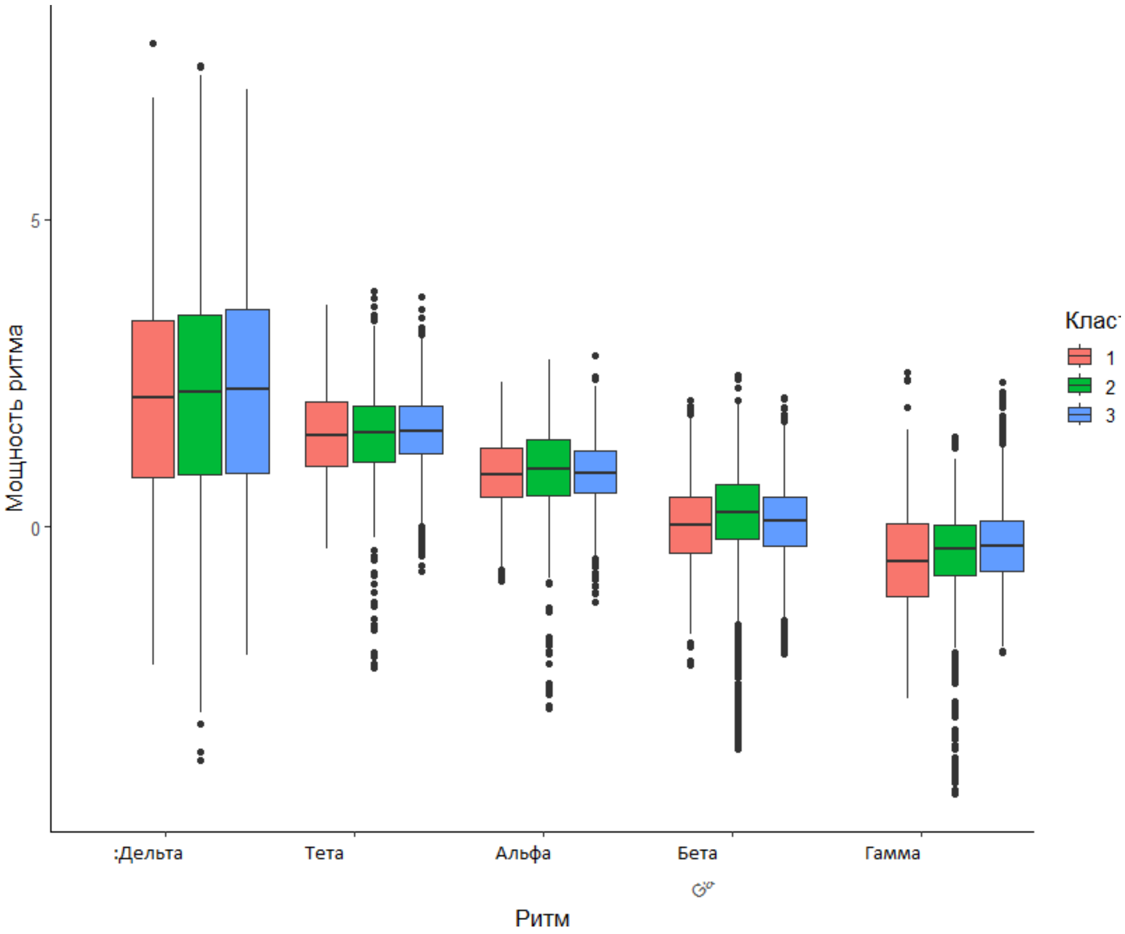

Figure 11 - Distribution of the power of rhythms in the process of formulating sentences depending on the cluster

Notes: Clusters; 1 - Level of development of executive functions below average, 2 - Level of development of executive functions on the border of average, 3 - Level of development of executive functions above average.

A statistically significant interaction of the two predictors (rhythm and cluster) determining neurophysiological activity was found ((F (2, 51) = 6.22, $p < 0.001$). In turn, both predictors, Cluster (F (2, 36) = 17.38, $p < 0.001$) and rhythm (F(4, 18453) = 4514.79, $p < 0.001$), showed statistically significant differences.

According to Tukey's post-hoc criterion, no statistically significant differencewas shown for alpha and theta rhythms between the clusters. Whereas in beta rhythmwe can observe differences between clusters. The second cluster shows the highest activation compared to the other two (cluster 1: diff = 0.12, $p < 0.01$, cluster 2: diff = 0.09, $p < 0.05$). In Delta rhythm we observe a significant difference between the third and the first cluster (diff = 0.16, $p < 0.01$). And, in Gamma rhythm the third cluster shows the greatest activation (1 cluster: diff = 0.22, $p <0.001$, 2 cluster: diff = 0.17, $p <0.001$).

3.7. Comparative analysis of two experiments

Further analysis was aimed at determining group differences between the two experimental conditions: copying a sentence from memory and typing a formulated sentence from a picture. We hypothesized that the spectral power of high-frequency rhythms would be significantly higher in the group in which participants typed sentences from a picture, and that high-frequency rhythms would be less pronouncedin participants who were shown to have higher development of executive functions.To test this hypothesis, we performed a two-factor analysis of variance (ANOVA) with repeated measures. Preliminarily, the spectral power indices were checked fornormal distribution and the homogeneity of variances was calculated. The dependent variable was the spectral power of each rhythm. The variables group andtype of experiment acted as independent variables. The behavioral indices of interest(the UNIT Memory Index and the BRIEF-2 Inhibition, Working Memory, and Switching Indices) served as covariates.

A linear mixed model (LMM) with repeated measures was constructed to compare power density spectra between groups in the two experiments. Statistically significant differences in neurophysiological activity were observed across experiments (($\chi 2$ (2) = 1622.68, $p < 0.001$, $\eta = 0.14$ [CI: 0.14 - 1]. At the same time,depite statistically significant differences between groups in different experiments, no significant effect was found (($\chi 2$ (2) = 37.72, $p < 0.001$, $\eta = 0.001$ [CI: 0.00 - 1].

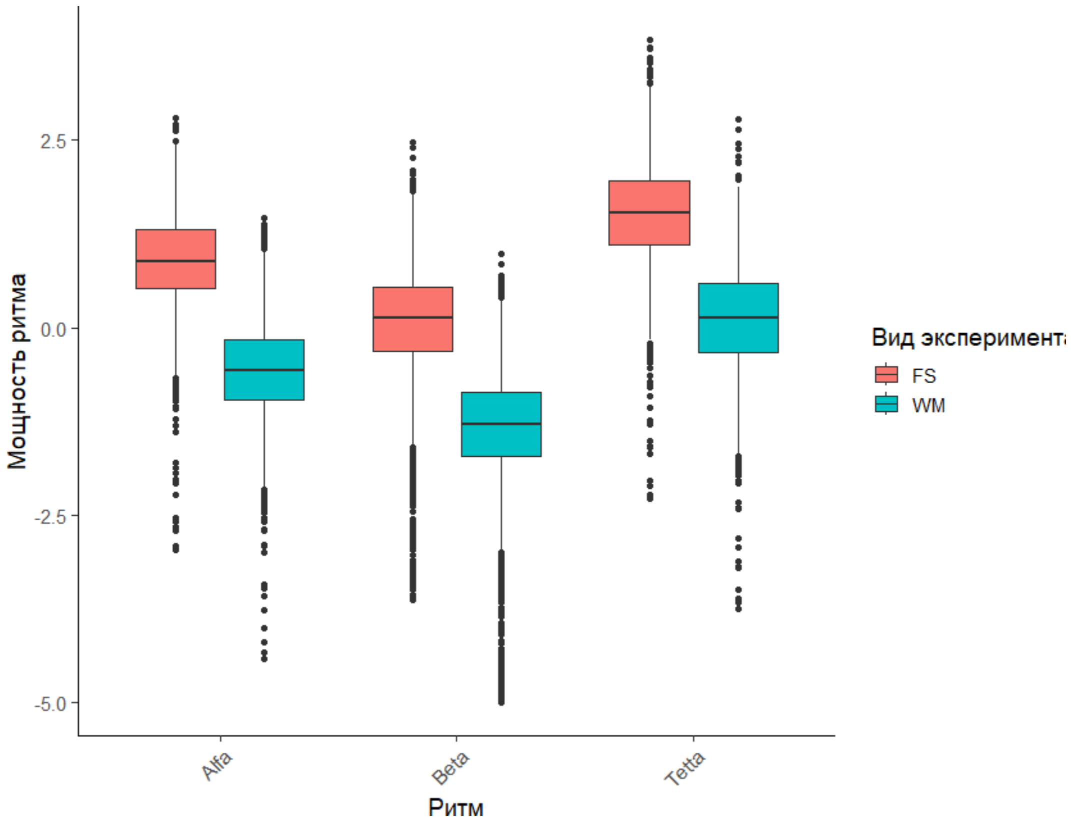

Figure 9 – Differences in power spectral density between experiments

Notes: FS is a formulation sentence experiment, WM is a copying sentences experiment

The results demonstrated statistically significant differences between the experiments. According to Tukey's post-hoc test (diff = -2.22, p <.001), alpha rhythm power density in the sentence copying (WM) experiment was lower (M(SD) = 0.69 (0.49)) than in the sentence formulation (FS) experiment (M (SD) = 2.91 (1.95)). In the beta range, according to Tukey's post-hoc criterion (diff = -1.03, p < 0.001), mean beta rhythm power density was significantly lower in WM (M(SD) = 0.33 (0.23)) than in FS (M(SD) = 1.37 (0.96)). At the same time, according to Tukey's post-hoc criterion (diff = -4.47, p < 0.001), theta power density in WM waslower (M(SD) = 0.69 (1.32)) than in FS (M(SD) = 5.94 (4.98)).

Table 9 - LMM model result for power density of spectral rhythms between groups

Predictors	Estimates	CI	p
(Intercept)	2.83	2.62 – 3.05	**<0.001**
Group [EG]	0.15	-0.17 – 0.46	0.359
Exp [WM]	-2.13	-2.27 – -1.99	**<0.001**
Rhythm [beta]	-1.45	-1.56 – -1.34	**<0.001**
Rhythm [theta]	2.84	2.70 – 2.99	**<0.001**
Group [EG] * Exp [WM]	-0.16	-0.36 – 0.05	0.131
Group [EG] * Rhythm [beta]	-0.19	-0.35 – -0.03	**0.019**
Group [EG] * Rhythm [theta]	0.38	0.17 – 0.59	**<0.001**
Exp [WM] * Rhythm [beta]	1.10	0.94 – 1.25	**<0.001**
Exp [WM] * Rhythm [theta]	-2.00	-2.20 – -1.80	**<0.001**
(Group [EG] * Exp [WM] * Rhythm [beta]	0.19	-0.03 – 0.41	0.097
(Group [EG] * Exp [WM] * Rhythm[theta]	-0.50	-0.79 – -0.21	**0.001**
Random Effects			
σ2	02.03		
τ00 ID	0.23		
ICC	0.10		
N ID	48		
Observations	22862		
Marginal R2 / Conditional R2	0.454 / 0.510		

Notes. Memory - Memory Index, UNIT-2; Inhibit - Inhibit Index, BRIEF-2; WM - Working Memory Index, BRIEF-2; Shift - Shift Index, BRIEF-2. Types of experiments: WM - sentence copying experiment, FS - sentence formulation experiment. EG - experimental group, CG - control group. Statistically significant values are shown in bold.

3.8. Discussion

In the field of typing, the processes involved in formulating sentences and physically typing words can occur simultaneously and independently, rather than being organized hierarchically [64]. This means that the motor actions and error control of typing can operate at the same level without a clear hierarchy. However, when it comes to controlling arbitrary movements, executive control plays a role in regulating a sequence of prints based on the purpose and taskat hand. This triggers motor programs that are organized hierarchically, allowing forthe coherent representation of complex motor acts like words or sentences. These motor programs also include mechanisms for correcting errors at the individual element level [72]. Therefore, both parallel processes (such as inhibition and working memory) and sequentially organized processes (such as inhibition and switching) are observed during typing.

The beta rhythm, which is a type of brainwave activity, is present during tasksthat require focused attention (Lundqvist et al., 2018). It reflects the balance between inhibitory and excitatory processes in the brain. Consequently, the power of the beta rhythm can be considered as an indicator of the information processing and motor command generation during the typing process [57]. The interplay between these indicators, such as inhibition and switching or inhibition and working memory as measured by the BRIEF-2 technique, has a significant impact on the distribution of neural activation in the frontal and prefrontal cortex. These findings align with previous studies on executive control [26]; [30]; [117] and working memory памяти [98]. Based on these observations, it is possible to identify a set of neurophysiological indicators that reflect the level of cognitive load during the typing process.

Executive control plays a significant role in both direct typing and the processof sentence formulation [72]. It encompasses feedback loops thatregulate both the overall process of typing a sentence and the individual motor actions involved. The level of executive control involvement depends on the development and automation of typing skills. Executive control is responsible for goal setting, planning, monitoring, and evaluating outcomes [1].Our findings indicate that individuals with higher typing skills demonstrate better executive control, consistent with previous studies showing that higher typing skills require less cognitive effort and activate inhibition processes more effectively, resulting in improved executive control performance [30]; [95]. Therefore, automating typing enables more successful execution of complex sentence formulation tasks [58]. Furthermore, once a skill becomes automated, cognitive resources become available for other tasks.

Regarding the interaction of executive functions, working memory and executive control can interact in the following ways: (1) control of information processing and (2) filtering or suppression of irrelevant information. Executive control is integrated into working memory processes by deliberately maintaining one goal while suppressing competing ones. When focused on a specific task, such as writing, it is necessary to ignore external stimuli. The more effective the inhibition processes, the easier it becomes to maintain concentration. During copying, participants are required to remember the presented text, hold it in working memory,and type what they remember. This necessitates the activation of working memory and concentration on a single task.

Numerous studies have highlighted the correlation between task complexity, concentration, and the detrimental effects of external distractions, both in the contextof sentence copying and formulation. While copying sentences is a relatively simplertask, studies investigating the combination of executive control and working memory shed light on the importance of suppressing irrelevant stimuli. For instance, well-known experiments involving dichotomous delivery of different auditory stimuli to each ear demonstrated that participants who failed to reduce the relevanceof additional tasks performed poorly on the primary task of letter and number alternation.

The task of sentence formulation requires the ability to construct grammatically and syntactically correct complex sentences. Although no statistically significant differences in executive function were observed between groups, variations in beta rhythm may indicate differences in cognitive difficulty between tasks. Previous research on executive control has shown that activating motor memory, such as the automatization of typing, is associated with increased inhibitionin the prefrontal area, accompanied by an increase in beta rhythm [115]. In this study, the increase in beta rhythm during sentence copyingin the premotor area reflects a general tendency to engage motor memory.

The process of generating, formulating, and subsequently typing text involvesnot only the motor patterns associated with typing but also cognitive efforts relatedto text generation. These processes engage spatial and verbal thinking, executive attention, and working memory [47]; [64]; [93]. In automated typing, cognitive functions play a smaller role, andtyping is primarily driven by mechanical processes and working memory [118]. In non-automated typing, the combination of sequential repetitive typing movements is facilitated by inhibiting motor impulses from higher-level structures [21]; [74]; [94]. Consequently, as the pattern becomes more automated, the inner loop becomes more involved, while the outer loop plays a lesser role (Crump & Logan, 2010).

However, both in the case of copying and sentence formulation, the interaction between Working Memory and Inhibition contributes to the power of thebeta rhythm in the forebrain [30]. Working memory plays a crucial role in typing by serving as a buffer for storing, processing, and transferring information. The resource allocation model suggests that more complextasks place a greater load on working memory. Additionally, higher skill levels in automated writing are associated with faster processes in working memory. Therefore, it can be argued that working memory is involved in retaining words andimages during complex non-automated activities like sentence formulation [28]; [95]. This is supported by increased power of beta activity in the prefrontal and frontal regions [67].

Furthermore, the results of this study indicate that beta activity decreases withan increase in the Switching index. The prefrontal cortex is known to be involved in differentiating attention resources and switching attention to stimuli (Rikhye, Gilra,&

Halassa, 2018). Hence, it can be speculated that participants with higher switching abilities require less cognitive load to maintain attention on a task [96]. These findings indirectly suggest the involvement of switching processes in the task of sentence formulation. Research also demonstrates that blind and semi- blind typing skills reduce cognitive load [93], further supporting the role of switching in this task. Consequently, participants with higher abilities find the task easier to perform.

To summarize, during the process of sentence formulation, the cognitive load,as indicated by beta power, decreases as the level of switching and inhibition development increases. The analysis of neuronal activation in both tasks revealed notable differences, particularly in the alpha, beta, and theta rhythms, where the sentence-forming task exhibited significantly higher levels of load. The disparity in beta rhythm activity suggests that copying complex but meaningless sentences, which require a high resource load according to working memory theory (Chai et al., 2018), is less likely to engage the beta rhythm associated with complex tasks. Furthermore, the presence of theta activity in the frontal-medial area during text copying (Meckler et al., 2010) indicates an overall increase in cognitive load duringtyping. In contrast, the process of sentence formulation entails a much higher level of cognitive load as it involves not only the typing process and the activation of executive and cognitive functions but also internal speech processes (García-Marcoet al., 2019). Consequently, higher-frequency rhythms are more prominently activated during this process compared to the typing of recalled sentences.

Conclusions

Based on the hypotheses formulated and the results obtained, the following conclusions can be made:

1. The results obtained between the methods BRIEF-2 and UNIT-2, which measure the level of development of executive functions, illustrate a high correlationin terms of indicators within the methods (Inhibition, Switching and Working Memory), whereas this trend is not observed between the methods. Accordingly, these techniques cover different domains of executive functions.

2. A statistically significant contribution of the level of inhibition development to the percentage of correctly typed words is observed. Accordingly, itcan be assumed that the more efficient the inhibition processes, the higher the accuracy of the typed words. On this basis, the higher the accuracy of the written word, the better developed the inhibition skill of the respondent. The rest of the behavioral characteristics did not show statistical significance.

3 The model that best describes the variance of activation of alpha, beta, andtheta rhythm powers during typing includes predictors such as working memory, inhibitory process severity, and level of attention switching.

3.1 Significant contributions of inhibition, switching, and working memory measures to alpha, beta, and theta rhythm power during copying of a recalled sentence were shown. At the same time, significant differences in gamma and deltarhythms were observed in the clusters formed by the level of development of executive functions. The power of the beta rhythm is an indicator of the mechanismof information processing and the issuance of motor commands during typing. Significant influence of alpha and theta rhythms shows balance of inhibitory and excitatory processes. It illustrates a principle of work of motor memory, and also isreflected in activation of theta and alpha rhythms in a frontal and prefrontal cortex that coincides with results of research of the executive control and working memory.

3.2 A significant contribution of working memory and inhibition to the power of alpha, beta, and theta rhythms was found when printing an image-formulated sentence. In the beta rhythm, a higher activation can be observed in the cluster with average values for all measures. Which may indicate that the cognitive load in the group, with high indicators is lower, due to the accumulated skill. Whereas a higheralpha rhythm provided a balance of inhibitory processes in the other two groups. Also, our results show that respondents with higher typing skill demonstrated betterexecutive control, because high typing skill required less cognitive effort and thus less activation of inhibition, working memory, and switching processes. And, also, when an automated skill is formed, a resource is freed up to use cognitive functionsto perform other tasks.

4. Significant differences in neutron activity between the types of experiments were observed. The power in alpha, beta, and theta rhythms was lowerin the sentence copying experiment than in the sentence formulation experiment. The difference in beta rhythm may say that copying complex, meaningless sentences, which require a large resource load, according to working memory theory,activates the beta rhythmics that occurs during complex tasks to a lesser extent. According to the available data, the appearance of theta activity in the frontal-medialarea when copying text is indicative of an overall increase in cognitive load in the printing process.

Resume

All tasks assigned in the present study have been successfully completed. The study aimed to investigate the psychophysiological and behavioral characteristics of executive functions during typing and develop models of executive functions basedon the set objectives. The study's scientific significance lies in identifying psychophysiological patterns of executive functions during typing, a complex process that involves both executive and cognitive functions. The difference between typing tasks that involve copying sentences and tasks that require formulating new sentences can be observed through the activation of high-frequencyrhythms in frontal, prefrontal, and motor areas. Previous research suggests that typing induces high levels of stress in premotor and motor areas only when additional typing tasks are introduced. On the other hand, copying text or a sentenceexhibits a lower frequency load due to the automated nature of the activity. Consequently, respondents who exhibit automated typing skills (typing speed above150 characters per minute and accuracy above 97%) are suitable candidates for investigating the more complex cognitive processes involved in typing [72], [102].

Logan and Crump's (2011) hierarchical theory of typing suggests that executive functions play an important role in all stages of typing and can be trainedusing this tool. This study provided evidence of the involvement of executive control, working memory, inhibition, and switching processes in sentence typing, whether recalling given sentences or formulating new ones. The motor component,motor memory, is also involved in this hierarchical process and is relevant for diagnosing or preventing degenerative diseases. The study demonstrated that the development of executive functions is crucial to typing, and print-based simulatorscan be used to train them. This practical contribution could benefit respondents with cognitive or executive function impairments by providing them with various levels of difficulty in typing simulators. As typing is a common activity, this training could be accessible to any segment of the population. Furthermore, popularizing the idea that typing can enhance cognitive and executive functions may motivate older people to learn computer typing, thus addressing the current social problem of age groups struggling to learn computer typing. The study alsosuggested that the findings could be used to develop better ways of typing by training neural networks using the psychophysiological data collected.

List of papers published on the results of the dissertation research

1. Andriyanova N.V., Bakuleva K.K., Petrov M.V., Golovanova I.V., Momotenko D.A., Abramenkov A.I. Psychological and neurophysiological features of the manifestation of contradictions in social perception depending on the type of initial information about a person // Internet Journal "World of Science" 2017, Volume 5, Number 6
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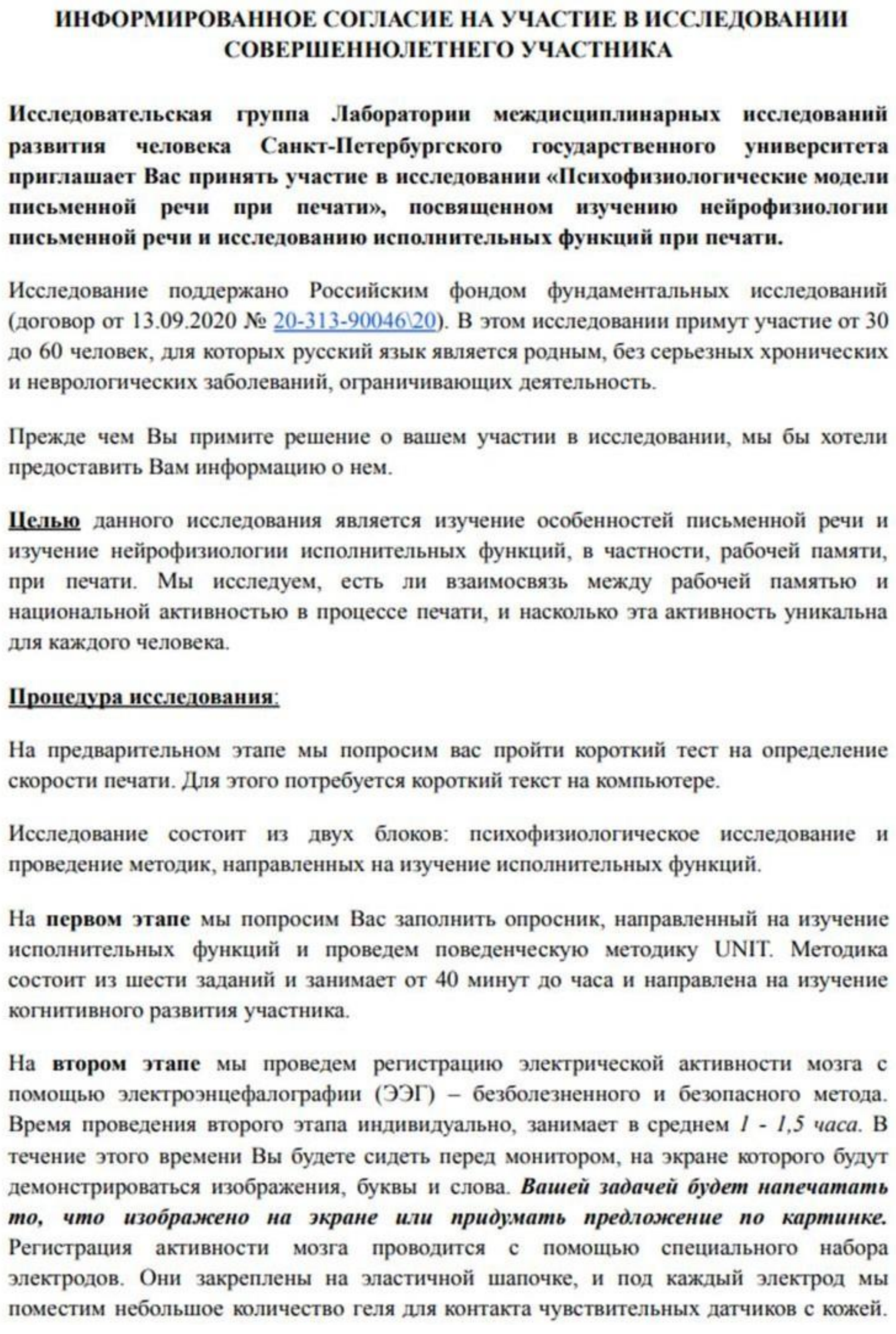
Appendix 1: Informed Consent



ИНФОРМИРОВАННОЕ СОГЛАСИЕ НА УЧАСТИЕ В ИССЛЕДОВАНИИ СОВЕРШЕННОЛЕТНЕГО УЧАСТНИКА

Исследовательская группа Лаборатории междисциплинарных исследований развития человека Санкт-Петербургского государственного университета приглашает Вас принять участие в исследовании «Психофизиологические модели письменной речи при печати», посвященном изучению нейрофизиологии письменной речи и исследованию исполнительных функций при печати.

Исследование поддержано Российским фондом фундаментальных исследований (договор от 13.09.2020 № 20-313-90046\20). В этом исследовании примут участие от 30 до 60 человек, для которых русский язык является родным, без серьезных хронических и неврологических заболеваний, ограничивающих деятельность.

Прежде чем Вы примите решение о вашем участии в исследовании, мы бы хотели предоставить Вам информацию о нем.

Целью данного исследования является изучение особенностей письменной речи и изучение нейрофизиологии исполнительных функций, в частности, рабочей памяти, при печати. Мы исследуем, есть ли взаимосвязь между рабочей памятью и национальной активностью в процессе печати, и насколько эта активность уникальна для каждого человека.

Процедура исследования:

На предварительном этапе мы попросим вас пройти короткий тест на определение скорости печати. Для этого потребуется короткий текст на компьютере.

Исследование состоит из двух блоков: психофизиологическое исследование и проведение методик, направленных на изучение исполнительных функций.

На **первом этапе** мы попросим Вас заполнить опросник, направленный на изучение исполнительных функций и проведем поведенческую методику UNIT. Методика состоит из шести заданий и занимает от 40 минут до часа и направлена на изучение когнитивного развития участника.

На **втором этапе** мы проведем регистрацию электрической активности мозга с помощью электроэнцефалографии (ЭЭГ) – безболезненного и безопасного метода. Время проведения второго этапа индивидуально, занимает в среднем *1 - 1,5 часа*. В течение этого времени Вы будете сидеть перед монитором, на экране которого будут демонстрироваться изображения, буквы и слова. ***Вашей задачей будет напечатать то, что изображено на экране или придумать предложение по картинке.*** Регистрация активности мозга проводится с помощью специального набора электродов. Они закреплены на эластичной шапочке, и под каждый электрод мы поместим небольшое количество геля для контакта чувствительных датчиков с кожей.

По окончании обследования гель можно стереть или вымыть и высушить волосы. Данная процедура абсолютно безболезненна и безопасна. Используемое нами электрофизиологическое оборудование сертифицировано в России и соответствует международным стандартам безопасности.

Выгоды:

За участие в исследовании мы предлагаем участникам компенсацию в виде подарка эквивалентом 1000 рублей (одна тысяча рублей) . Для получения вознаграждения участникам необходимо пройти все этапы исследования (поведенческие методики, заполнение опросников и ЭЭГ-исследование). Вознаграждение вручается участникам сразу после окончания исследования.

Добровольность участия: мы очень надеемся на Ваше участие во всех блоках исследования, при этом хотим отметить, что участие в данном исследовании полностью добровольно. Участник исследования может принять решение не отвечать на определенные вопросы. Это решение не повлечет за собой никаких мер.

Конфиденциальность: Вся собранная информация абсолютно конфиденциальна и будет доступна только членам исследовательской группы. Всем участникам исследования приписываются идентификационные номера, которые вводятся в защищенную зашифрованную компьютерную базу данных. Результаты исследования будут представлены на конференциях и в научных публикациях только в групповой форме (т.е. как описание совокупности участников, а не отдельных людей). Полученная информация не будет сообщаться в образовательное учреждение, в котором учится Ваш ребенок.

По всем вопросам, связанным с исследованием, обращайтесь к координатору:

Дарья Момотенко, телефон: +7 951 672 44 78 или +7 911 083 49 42

Данное исследование рассмотрено и одобрено Этическим комитетом Института психологии Российской академии наук (ИП РАН), куда Вы можете обратиться, если у Вас возникнут вопросы: [**телефон: +7(495) 683-38-09; e-mail: adm3@psychol.ras**].

Я, ____ (ФИО)
даю свое согласие на участие в данном исследовании.

Мне разъяснены условия участия и процедура проведения обследования.

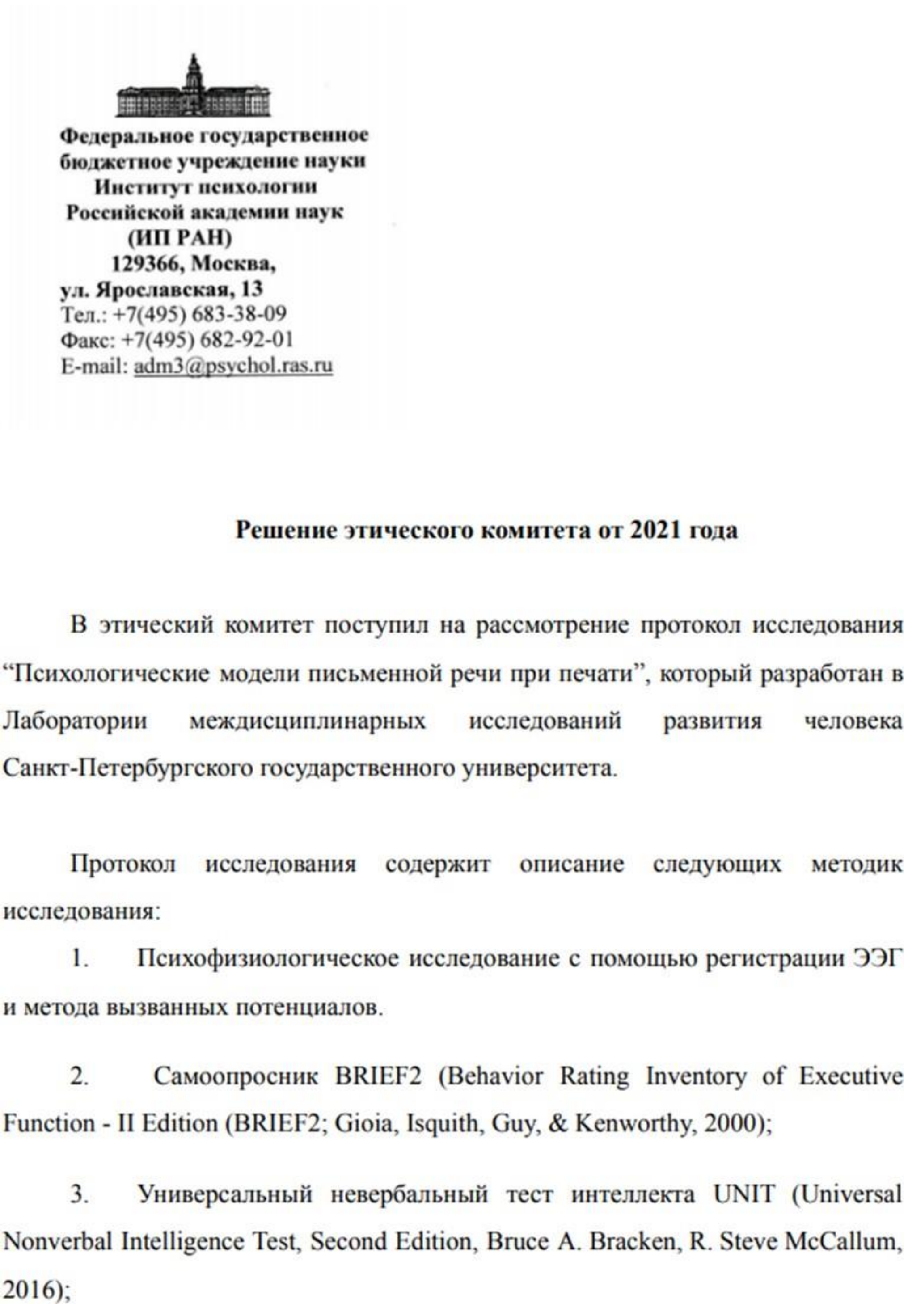
Дата ______________

Подпись участника _________________

Подпись представителя проекта__________________

Контактные данные ______________________________

Appendix 2: Ethics Committee Approval



**Федеральное государственное
бюджетное учреждение науки
Институт психологии
Российской академии наук
(ИП РАН)
129366, Москва,
ул. Ярославская, 13**
Тел.: +7(495) 683-38-09
Факс: +7(495) 682-92-01
E-mail: adm3@psychol.ras.ru

Решение этического комитета от 2021 года

В этический комитет поступил на рассмотрение протокол исследования “Психологические модели письменной речи при печати”, который разработан в Лаборатории междисциплинарных исследований развития человека Санкт-Петербургского государственного университета.

Протокол исследования содержит описание следующих методик исследования:

1. Психофизиологическое исследование с помощью регистрации ЭЭГ и метода вызванных потенциалов.

2. Самоопросник BRIEF2 (Behavior Rating Inventory of Executive Function - II Edition (BRIEF2; Gioia, Isquith, Guy, & Kenworthy, 2000);

3. Универсальный невербальный тест интеллекта UNIT (Universal Nonverbal Intelligence Test, Second Edition, Bruce A. Bracken, R. Steve McCallum, 2016);

4. Культурно независимый тест интеллекта Кеттелла (Culture fair intelligence test, Scale 2; CFIT; Cattell & Cattell, 1960);

5. Оценка превалирующей в использовании руки (Oldfield, R.C. "The assessment and analysis of handedness: the Edinburgh inventory." Neuropsychologia. 9(1):97-113. 1971).

Этический комитет постановил следующее:

1. Одобрить протокол исследования, “Психологические модели письменной речи при печати”, который разработан в Лаборатории междисциплинарных исследований развития человека Санкт-Петербургского государственного университета.
2. Признать предложенные методики безопасными для физического и психического здоровья участников исследования.
3. Разрешить использование данных методик как для взрослых, так и для несовершеннолетних участников исследования.
4. Утвердить порядок получения письменного информированного согласия для участия в исследовании:
   - согласие на участие в исследовании лиц старше 14 лет должно быть зафиксировано в письменном информированном согласии, которое подписывается самими участниками исследования.

Председатель этического комитета

зам. директора ИП РАН,
чл.-корр. РАН А.В. Юревич

Appendix 3. Stimulus material for the EEG experiment «Copying sentences»

1. ej ciryul'nik" yozhik vystrigi da shchetinu ryahi sbrej fenom vosh' za pech' goni
2. shalyashchij favn prikinul ob"yom goryachih zvezd etih v'yuzhnyh carstv
3. pishi zyat' s"el yajco eshchyo chan bryukvy... ekh - zhdem figu
4. flegmatichnaya eta verblyudica zhuet u pod"ezda zasyhayushchij gor'kij shipovnik
5. ekh vz"yaryus' tolknu flegmatika - dal by shchec zharchajshih pyotr
6. vstupiv v boj s shipyashchimi zmeyami - efoj i gadyukoj - malen'kij cepkij hrabryjyozh s"el ih
7. odnazhdy s"ev fejhoa ya kak zaciklennyj nostal'giruyu vsyo chashche i bol'she poetomu chudu
8. rascheshis'. ob"yavlyayu - tufli u kamina gde etot hishchnyj yozh caplyu zadel
9. shifroval'shchica poprostu zabyla ryad klyuchevyh mnozhitelej i tegov
10. yuzhno-efiopskij grach uvel mysh' za hobot na s"ezd yashcheric
11. shirokaya elektrifikaciya yuzhnyh gubernij dast moshchnyj tolchok pod"yomusel'skogo hozyajstva
12. des' fabula ob"yat' ne mozhet vsekh emocij — shepelyavyj skorohod v yubke tashchit goryachij myod
13. hudozhnik-ekspert s komp'yuterom vsego lish' yajca v ob"yomnyj nizkij yashchikchohom fasoval

Appendix 4: Stimulus material (words) for the EEG experiment «Formulation of sentences»

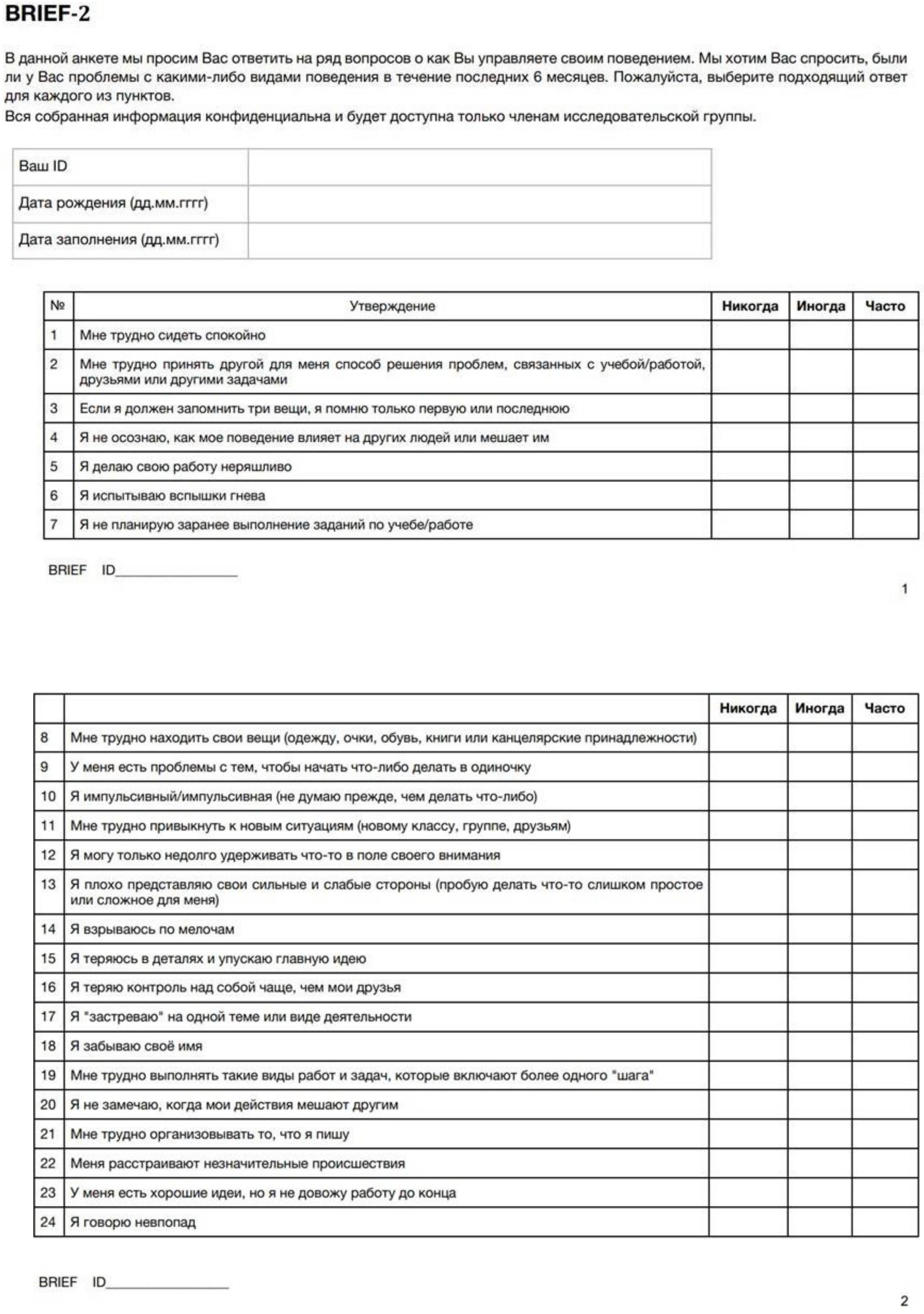
1. after ... before
2. read
3. it
4. and ... therefore
5. despite
6. в
7. quickly
8. finally
9. if ... then ...
10. machine
11. third
12. first
13. before ... otherwise
14. because
15. plane
16. best
17. instead of
18. prepare
19. when
20. before
21. even ... if
22. and ... or
23. and
24. if

Appendix 5. Stimulus material (example images) for the EEGexperiment «Formulation of sentences»

Когда

Или … и

Appendix 6. BRIEF-2 questionnaire form



BRIEF-2

В данной анкете мы просим Вас ответить на ряд вопросов о как Вы управляете своим поведением. Мы хотим Вас спросить, были ли у Вас проблемы с какими-либо видами поведения в течение последних 6 месяцев. Пожалуйста, выберите подходящий ответ для каждого из пунктов.
Вся собранная информация конфиденциальна и будет доступна только членам исследовательской группы.

Ваш ID	
Дата рождения (дд.мм.гггг)	
Дата заполнения (дд.мм.гггг)	

№	Утверждение	Никогда	Иногда	Часто
1	Мне трудно сидеть спокойно			
2	Мне трудно принять другой для меня способ решения проблем, связанных с учебой/работой, друзьями или другими задачами			
3	Если я должен запомнить три вещи, я помню только первую или последнюю			
4	Я не осознаю, как мое поведение влияет на других людей или мешает им			
5	Я делаю свою работу неряшливо			
6	Я испытываю вспышки гнева			
7	Я не планирую заранее выполнение заданий по учебе/работе			

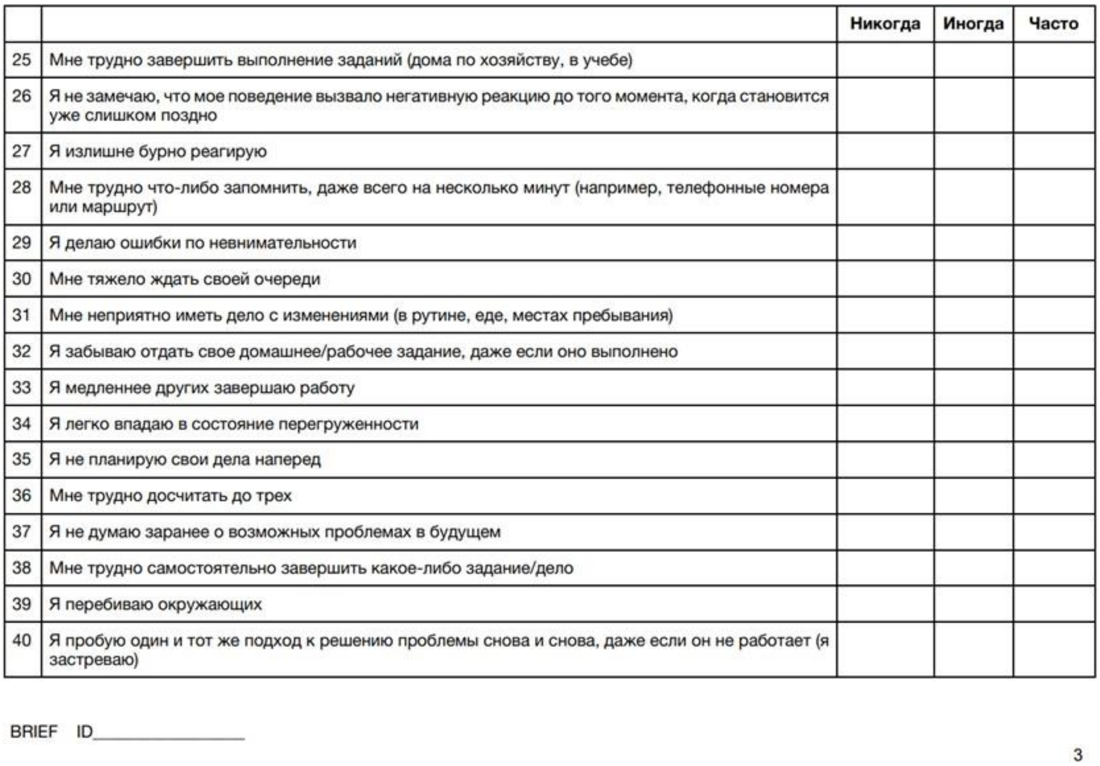
BRIEF ID________________

1

		Никогда	Иногда	Часто
8	Мне трудно находить свои вещи (одежду, очки, обувь, книги или канцелярские принадлежности)			
9	У меня есть проблемы с тем, чтобы начать что-либо делать в одиночку			
10	Я импульсивный/импульсивная (не думаю прежде, чем делать что-либо)			
11	Мне трудно привыкнуть к новым ситуациям (новому классу, группе, друзьям)			
12	Я могу только недолго удерживать что-то в поле своего внимания			
13	Я плохо представляю свои сильные и слабые стороны (пробую делать что-то слишком простое или сложное для меня)			
14	Я взрываюсь по мелочам			
15	Я теряюсь в деталях и упускаю главную идею			
16	Я теряю контроль над собой чаще, чем мои друзья			
17	Я "застреваю" на одной теме или виде деятельности			
18	Я забываю своё имя			
19	Мне трудно выполнять такие виды работ и задач, которые включают более одного "шага"			
20	Я не замечаю, когда мои действия мешают другим			
21	Мне трудно организовывать то, что я пишу			
22	Меня расстраивают незначительные происшествия			
23	У меня есть хорошие идеи, но я не довожу работу до конца			
24	Я говорю невпопад			

BRIEF ID________________

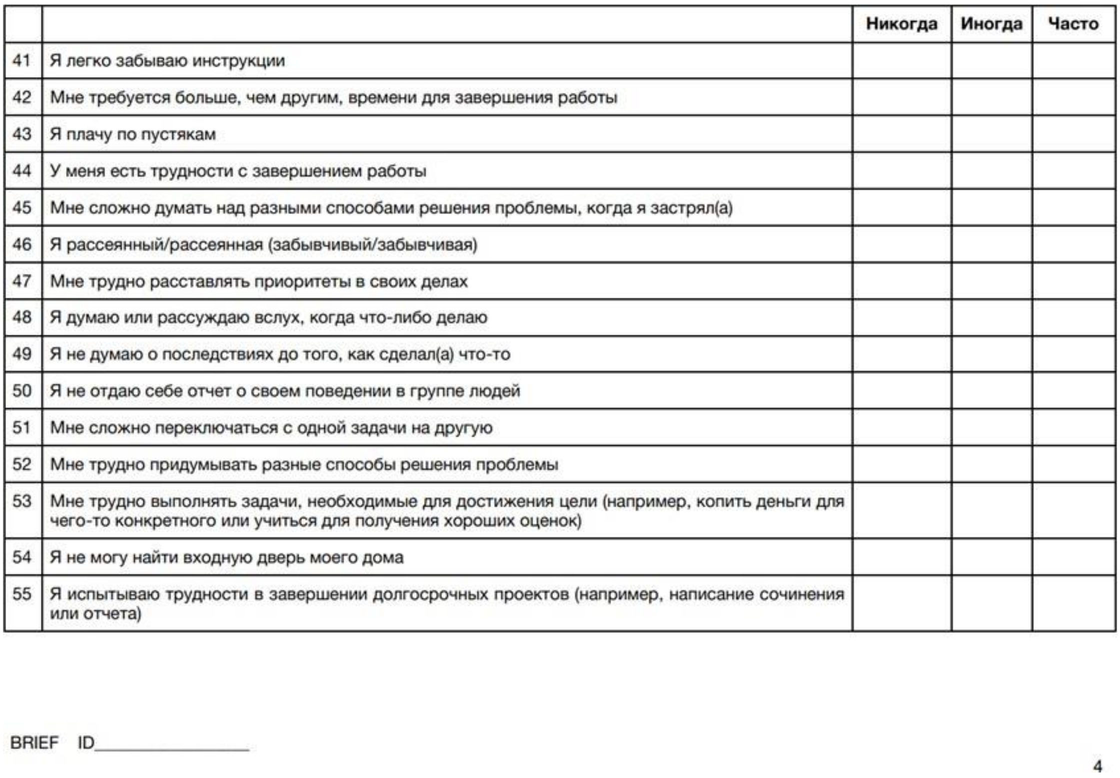
2



		Никогда	Иногда	Часто
25	Мне трудно завершить выполнение заданий (дома по хозяйству, в учебе)			
26	Я не замечаю, что мое поведение вызвало негативную реакцию до того момента, когда становится уже слишком поздно			
27	Я излишне бурно реагирую			
28	Мне трудно что-либо запомнить, даже всего на несколько минут (например, телефонные номера или маршрут)			
29	Я делаю ошибки по невнимательности			
30	Мне тяжело ждать своей очереди			
31	Мне неприятно иметь дело с изменениями (в рутине, еде, местах пребывания)			
32	Я забываю отдать свое домашнее/рабочее задание, даже если оно выполнено			
33	Я медленнее других завершаю работу			
34	Я легко впадаю в состояние перегруженности			
35	Я не планирую свои дела наперед			
36	Мне трудно досчитать до трех			
37	Я не думаю заранее о возможных проблемах в будущем			
38	Мне трудно самостоятельно завершить какое-либо задание/дело			
39	Я перебиваю окружающих			
40	Я пробую один и тот же подход к решению проблемы снова и снова, даже если он не работает (я застреваю)			

BRIEF ID_______________

3



		Никогда	Иногда	Часто
41	Я легко забываю инструкции			
42	Мне требуется больше, чем другим, времени для завершения работы			
43	Я плачу по пустякам			
44	У меня есть трудности с завершением работы			
45	Мне сложно думать над разными способами решения проблемы, когда я застрял(а)			
46	Я рассеянный/рассеянная (забывчивый/забывчивая)			
47	Мне трудно расставлять приоритеты в своих делах			
48	Я думаю или рассуждаю вслух, когда что-либо делаю			
49	Я не думаю о последствиях до того, как сделал(а) что-то			
50	Я не отдаю себе отчет о своем поведении в группе людей			
51	Мне сложно переключаться с одной задачи на другую			
52	Мне трудно придумывать разные способы решения проблемы			
53	Мне трудно выполнять задачи, необходимые для достижения цели (например, копить деньги для чего-то конкретного или учиться для получения хороших оценок)			
54	Я не могу найти входную дверь моего дома			
55	Я испытываю трудности в завершении долгосрочных проектов (например, написание сочинения или отчета)			

BRIEF ID_______________

4