UDC 612.821
DOI: 10.31651/2076-5835-2018-1-2025-2-49-60

Volodymyr Serhiyovych Lyzohub
Cherkasy Bohdan Khmelnytskyi National University
v_lizogub@ukr.net
ORCID https://orcid.org/0000-0002-3001-138X
Yuliya Vitaliyivna Koval
Cherkasy Bohdan Khmelnytskyi National University
uyla0077@ukr.net
ORCID ID: https://orcid.org/0000-0001-7160-5240
Oleksandr Oleksandrovich Bezkopylny
Cherkasy Bohdan Khmelnytskyi National University
aleksbezk1981@ukr.net
ORCID ID: https://orcid.org/0000-0001-7207-7590
Tetiana Volodymyrivna Kozhemiako
Cherkasy Bohdan Khmelnytskyi National University
kozhemako@ukr.net
ORCID ID: https://orcid.org/0000-0003-4752-4197

INTERACTION BETWEEN MOTOR AND COGNITIVE BRAIN SYSTEMS IN PERSONS WITH HEARING DEPRIVATION

Abstract. *The peculiarities of the functional interaction of motor and cognitive systems were investigated in 27 persons with hearing loss aged 17-18, and 24 peers with normal hearing function, under the condition of visual information processing in the go/go and go/no-go paradigm. The cognitive task in the go/no-go paradigm included determining the modality of the signal, the shape of the figure, the semantic meaning of the word, and a quick reaction (go) or inhibition of the motor act (no-go). The task in the go/go paradigm involved a rapid motor response to signals of different modalities.*

The speed characteristics of the visual response to verbal signals in the go/no-go paradigm depended on the state of auditory function. The response time to words in the go/no-go paradigm for individuals with hearing deprivation was statistically significantly longer, and the speed characteristics were lower than those with normal sensory function ($p = 0.031$). According to the speed of performance of the task in the go/no-go paradigm for verbal signals, a level of functional interaction of motor and cognitive systems ($r = 0.66$; $p = 0.043$) was higher in young people with hearing loss, than in persons with normal hearing ($r = 0.38$; $p = 0.046$).

The functional interaction of motor and cognitive systems, as well as the speed of task performance depended on the choice of the information processing mode. The speed of performance of the task for the go/go paradigm was higher in subjects with deprivation ($p = 0.026$) and normal auditory function ($p = 0.041$) than in the go/no-go paradigm. It was established that the functional interaction of the motor and cognitive systems of the brain during information processing in the go/no-go paradigm depends on the modality of the signals. For young people with derivation of auditory function in the go/no-go paradigm, the time characteristics of performing tasks for pictorial signals were statistically significantly higher than for verbal signals ($p = 0.028$), and for individuals with normal auditory function, such differences were ($p = 0.036$).

It has been proven that the functional interaction of the motor and cognitive systems of the brain depends on the complexity of the presented information, the modality of the signals, and the state of the sensory function. In case of dysfunction of the auditory system, the visual system is compensatory activated, and the intra- and intersystem functional interaction of the motor and cognitive systems of the brain is strengthened. A hypothesis is proposed, and the issue of the participation of distinct cross-modal mechanisms of functional interaction of cognitive and motor *systems of brain activity for persons with auditory function deprivation under the condition of visual information processing in the go/no-go paradigm is discussed.*

Key words: *hearing deprivation, go/no-go paradigm, motor and cognitive systems, information processing, reaction speed, signal modality.*

Nowadays, neurophysiological and pathophysiological processes occurring in the nervous system and brain are widely studied [1]. Researches and publications on the neurophysiological mechanisms of interaction between neurons were awarded the Nobel Prizes [2]. However, the mechanisms of the formation of integrative sensory, motor, and cognitive processes have not yet been elucidated. Scientists pay attention to problems in the study of signal transmission processes from the periphery of the nervous system to the brain, the mechanisms of their processing and transformation into sensations, emotions, cognitive processes, consciousness, speech, and behavioural reactions [3, 4].

It should be noted that the auditory system is the main sensory signaling system in a living organism and allows a person to navigate in time and space, perform important cognitive and behavioural functions. It reports on the occurrence of deviations from its normal functioning. Contemporary research shows that one of the important features of the human brain is its ability to process large volumes of information in parallel [5]. However, no matter how powerful this system is, it has its own sensitivity, limitations of attention and memory, ability to integrate and compete between ways of processing information. From this point of view, the functional interaction of the motor and cognitive systems of the brain is of significant scientific interest [6]. For this reason, the study of the interaction of the motor and cognitive systems of the brain under the conditions of information processing of various complexity and modality is paid great attention at the current stage of the development of neurocognitive science [7, 8, 9]. The literature describes various results of successful performance of cognitive and motor tasks [10, 11]. It has been established that the performance of a task can positively influence the result of another one [8]. It has been shown that listening to music increases the effectiveness of cognitive activity, concentration of attention, improves verbal and visual memory [7, 12]. Several studies have demonstrated changes in the quality of performing mental operations in the event of impaired ability to maintain balance or walking function [5]. There are the results of studies when motor function changes depending on the cognitive activity [12]. This gives reason to think that the functional organization of the brain is different for the performance of common cognitive and motor tasks.

It should be emphasized that most of the studies on elucidating the features of the functional interaction of the motor and cognitive systems were conducted on healthy subjects and based on the dominant principle. Therefore, to evaluate the results of the functional interaction of motor and cognitive systems, the number of correct answers or wrong reactions was mainly used without considering the speed characteristics of information processing. However, it is known that the speed characteristics of a simple sensorimotor reaction in the go/go mode are used to study the functional activity of the motor system [8, 13]. In our laboratory, the investigation and evaluation of the quantitative and qualitative characteristics of the interaction of the motor and cognitive systems is implemented under the condition of performing dual tasks in the go/no-go two-stimulus test paradigm [8]. First, we note that the choice reaction in the go/no-go mode includes excitatory signals (go), which need to be acted upon, but also inhibitory stimuli, to which motor reactions are not required (no-go). In this task, the success of the sensorimotor response will be determined by the speed of movement of excitation processes that compete with the characteristics of inhibition. We emphasize that the proposed two-stimulus go/no-go paradigm includes the processes of analysis and construction of a motor response program with the involvement of cognitive brain systems [14]. Therefore, research and assessment of the functional interaction of motor and cognitive systems under the condition of information processing in the go/no-go paradigm is promising and relevant for biological and medical science.

It should be noted that considerable clinical material on the dual performance of motor and cognitive tasks has already been accumulated [15, 16, 17] that proved to be extremely promising for evaluating the capabilities of people with cerebral pathology and in the conditions of attention distribution [18, 19]. Along with this, the psychophysiological foundations of the integrative function of the human brain during joint cognitive and motor activity are poorly studied. Since the functional model of task performance in the go/no-go two-stimulus paradigm includes various stages of cognitive and motor activity from motivation to the rapid performance of a motor act and control over the result of its performance, it became necessary to find out the features of the functional organization of cognitive and motor activity at the stage of altered sensory function. We believe that subjects with selective deprivation of auditory, visual, vestibular, olfactory, or gustatory functions could be a natural model for conducting an experiment. Lack of hearing causes changes in the sensory system from peripheral structures to the cortex, causes negative social consequences, and makes language acquisition impossible [20]. There is evidence that long-term deprivation of the auditory system is associated with the presence or absence of cross-modal plasticity and multisensory information processing [21]. Numerous data of neuroimaging that demonstrate the involvement of the visual areas of the brain of blind people in the processing of stimuli of the non-visual modality, particularly, auditory [22], speech perception [9, 23] testify in favour of the hypothesis of cross-modal plasticity. It was believed for a long time that cross-modal interaction is a consequence of the reorganization of the deafferented sensory cortex. There have been data indicating the modulation of the visual cortex in sighted people when performing auditory tasks. At the same time, some researchers note deactivation of the visual cortex of sighted people when performing auditory tasks [22], while others note activation [24], and others note simultaneous activation and deactivation of different areas of the sensory cortex [25].

Thus, there are a lot of data on the structural and functional reorganization of the deafferented sensory system in animals, blind and deaf people [21, 22, 23, 25]. The given results indicate the high plasticity of the sensory system in people with hearing deprivation, but its mechanisms have not been completely revealed to date. It can be assumed that in individuals with derivation, unlike those examined with normal hearing function, the processing of complex information in the go/no-go selection mode will be accompanied by various functional rearrangements in the interaction of the cognitive and motor systems of the brain. The question arises as to how the functional organization of the brain changes under conditions of performance of common cognitive and motor tasks in persons with sensory deprivation. The functional interaction of cognitive and motor systems and their mechanisms are still not sufficiently studied and remain debatable issues. Therefore, it is important to find out the peculiarities of the interaction of the motor and cognitive systems of the brain of persons with auditory function deprivation under the conditions of information processing in the go/no-go paradigm and their healthy peers. In this case, speed characteristics of sensorimotor reactions to various visual signals during information processing in the go/go and go/no-go paradigms is almost the only non-invasive method that directly registers functional changes in persons with hearing deprivation. The obtained results will allow a new approach to the analysis of the brain organization of various types of cognitive activity at the stage of motivation, perception, programming, decision-making, program performance and control over the obtained result [26]. We will also note the practical significance of research on the integrative functions of the brain during joint motor and cognitive activities for the development of ergonomic working conditions and rehabilitation of patients [27]. All the above determined the purpose, tasks, organization, and methods of the research.

The purpose of this study is to find out the peculiarities of the interaction of the motor and cognitive systems of the brain of persons with auditory function deprivation under the conditions of information processing in the go/go and go/no-go paradigm.

Materials and Methods. The peculiarities of the functional interaction of motor and cognitive systems were investigated under the condition of information processing in the go/go and go/no-go paradigm in 27 right-handed 17-18-year-old young men with derivation of hearing and 24 persons with normal hearing function. The absence of craniocerebral injuries and psychoneurological disorders, the state of health and the right-sided profile of manual and sensory asymmetry were considered when forming the contingent. Participation in the experiment was voluntary and complied with the bioethical norms of the Declaration of Helsinki. The subjects were informed and consented to participate in the study. They performed motor (go/go) and cognitive (go/no-go) information processing tasks of various modalities on the “Diagnost-1M” hardware and software complex. The reaction time and speed characteristics of a simple visual-motor reaction in the go/go paradigm and the reaction of choosing one of three signals in the go/no-go mode were determined [8].

Previously, the subjects learned the conditions and research algorithm, and preliminary trained. First, reaction time was determined in the go/go paradigm. The subject had to press the right button of the remote control as quickly as possible, if any shape appeared on the computer screen: «circle», «triangle» or «square». The second task was constructed like the first, with the only difference that in the go/go paradigm, subjects were presented with verbal signals: «animals», «objects» or «plants».

In the third task, the subject was presented with geometric shapes with the random presentation of go (response required) and conditioning no-go (no response) stimuli. The subject was asked to quickly press the right button (go) with the finger of the right hand upon the appearance of a «square» shape. The appearance of a «triangle» or «circle» is a brake signal not to press any button (no-go). The order of presentation of signals varied and was random. Exposure and pauses between signals were automatically changed from 0.5 to 1.9 s. The fourth test was constructed like the previous one, but verbal signals were presented. The subject performed the task in the go/no-go mode according to the instructions. When a word meaning «animal» appeared on the screen, he quickly pressed the right button (go) with the finger of his right hand, and when words meaning «objects» or «plants» were presented as an inhibitory stimulus, he did not press any button (no-go).

The average reaction time for go/no-go, separately for geometric shapes and verbal signals, was determined. To describe the sample distribution, Me [25; 75] (Me – median; 25 and 75 – lower and upper quartiles) was indicated. We calculated: the average value of indicators (M), the value of the average arithmetic error (±m), the mean square deviation (σ), the coefficient of variation (CV), the median and the 1^{st} and 3^{rd} quartiles (Me [25%; 75%]) for samples with a non-normal distribution, Wilcoxon (pairwise comparisons) or Mann-Whitney (comparisons of independent samples) significance tests. The data were also statistically processed using the ANOVA (two-way analysis of variance) system. Tukey's additivity test with Bonferroni correction was used to determine significant differences ($p < 0.05$).

Results. As a result of the conducted experiment, it was established that the functional interaction of the motor and cognitive systems under the condition of information processing depends on the modality of signals, the presence or absence of sensory deprivation, and the mode of presentation of signals (Table 1).

Table 1

Statistical indicators (Me [25%; 75%]) of performance speed of the motor (go/go) and cognitive tasks in the paradigm (go/no-go) for visual and verbal signals in persons with deprivation (n=24) and normal hearing function (n=27)

Motor and cognitive paradigm	Modality of signals					
	Shapes			Words		
	Hearing deprivation	Normal hearing	Statistical significance of the difference, p	Hearing deprivation	Normal hearing	Statistical significance of the difference, p
go/go, мс	228.4 [221.0;234.6]	236.1 [229.0;243.5]	0.067	231.5 [225.7;237.5]	238.4 [230.1;246.7]	0.075
go/no-go, мс	373.2 [366.6;379.7]	389.5 [383.5;395.3]	0.063	510.3* [503.5;517.0]	480.4* [473.3;487.3]	0.031
Statistical significance of the difference, P	0.027	0.034		0.041	0.026	

*Note * - statistical significance of differences in time characteristics of visual and verbal signals in persons with derivation of hearing (p=0.028) and normal sensory function (p = 0.036).*

Processing of information of different modalities in the go/go paradigm. In this task, all subjects made a quick reaction to the appearance of signals of different modalities in the go/go paradigm. The subject had to press and release the right button of his remote control as quickly as possible, provided that any shape («circle», «triangle», «square») appeared on the computer screen. The obtained results indicate that the motor reactions were the same in persons with normal sensory function and with derivation of auditory function (Fig. 1).

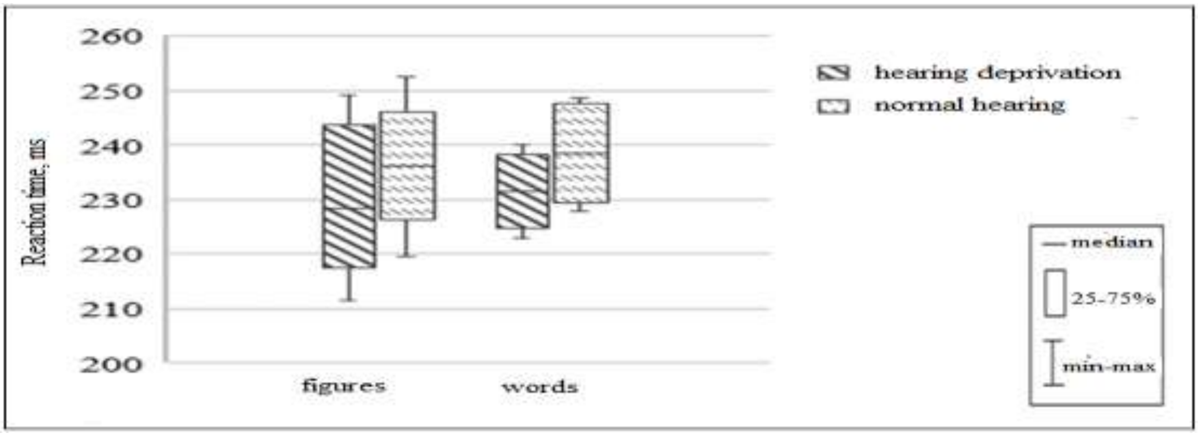

Fig. 1. Time of performing a task in the go/go paradigm to visual and verbal signals in subjects with deprivation and normal auditory function.

Thus, individuals with auditory function deprivation performed tasks in the go/go paradigm with pictorial signals at an average speed of 228.4 ms, and with normal sensory sensitivity - 236.1 ms. There were no statistically significant differences in the speed characteristics of the reaction time in the groups of subjects with normal auditory function and derivation of auditory function ($p = 0.067$).

Under the condition of performing the task in the go/go paradigm with verbal signals, the subject had to press and release the right button of his remote control as quickly as possible, if words meaning the names of «animals», «objects» or «plants» appeared on the monitor. The results indicate that the motor responses were the same in individuals with normal hearing function and with hearing derivation. Thus, persons with hearing deprivation performed this task at an average speed of 231.5 ms, and those with normal sensory sensitivity - 238.4 ms. No statistically significant differences in the speed characteristics of the go/go motor reaction time were found in the groups of subjects with normal auditory function and hearing derivation ($p=0.075$). We also found that the speed characteristics of the motor movement response in the go/go paradigm did not depend on the modality of the signals. The go/go reaction time to words and shapes was the same in subjects with derivation of auditory function ($p= 0.073$) and normal auditory function ($p= 0.068$).

Thus, the results of the conducted experiment established that the speed characteristics of the motor reaction in the go/go paradigm, provided that visual and verbal signals are presented, do not depend on the modality of the signals and the presence or absence of sensory deprivation.

Information processing in the go/no-go paradigm. The cognitive task required the subjects to perform a semantic analysis and a quick selective reaction to the appearance of signals of different modalities in the go/no-go paradigm. The subjects had to do a task performing a motor act as quickly as possible and press (go) the right button of the subject's remote control if a «square» appeared on the screen and not to press the (no-go) button is a «triangle» or «circle» signal appeared. The results of performing a cognitive task with visual signals were the same in persons with normal auditory function and with hearing derivation (Fig. 2). There were no statistically significant differences in the speed characteristics of reaction time with pictorial signals in the groups of subjects with normal auditory function and hearing derivation ($p = 0.063$).

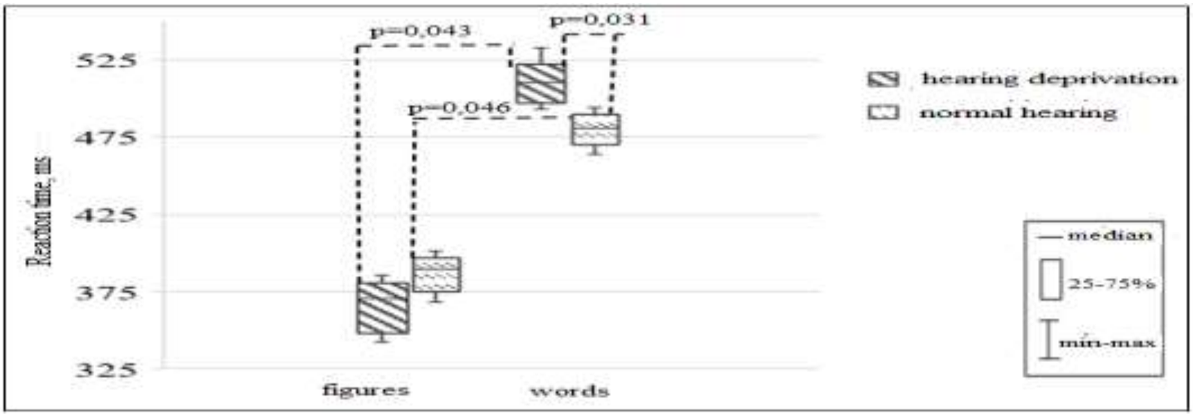

Fig. 2. Time of performing a cognitive task in the go/no-go paradigm to visual and verbal signals in subjects with derivation and normal auditory function.

In the case of a cognitive task on words in the go/no-go paradigm, subjects had to quickly respond to verbal signals. When a word meaning the name of «animal» appeared on the screen of the computer monitor, the subject was required to make a semantic analysis of the signals and quickly press the right button (go), and the subject's answer was not required - no-go for words meaning the name of «objects» or «plants». It was found that the time of the go/no-go cognitive reaction to words was statistically significantly longer in subjects with hearing deprivation than in subjects with normal hearing. Thus, individuals with auditory function deprivation performed a cognitive task on verbal signals in the go/no-go paradigm at an average speed of 510.3 ms, while those with normal sensory sensitivity were much faster - 480.4 ms ($p = 0.031$).

Thus, the results indicate that the speed characteristics of the go/go motor response to both verbal and visual signals were higher than in the go/no-go paradigm in subjects with normal auditory function and hearing derivation. Therefore, the speed characteristics of the motor reaction depended on the mode of presentation of the signals. They were higher for the go/go response and lower in the go/no-go paradigm. It should be emphasized that the speed characteristics of the response to verbal signals in the go/no-go paradigm depended on sensory deprivation. Response time to words in the go/no-go paradigm for individuals with sensory deprivation were statistically significantly longer and speed characteristics lower than those with normal hearing, while the speed characteristics of reactions in the go/no-go and go/go paradigms under the condition of presentation of visual signals did not depend on the state of the sensory function.

Discussion.

There are different ways of processing go/go, go/no-go and go/no-go/go information [8]. In the case of the go/no-go paradigm, it can be considered as a process of joint cognitive and motor activity, as well as competition between the ways of processing the relevant go (response is required) and the non-relevant no-go stimulus (no response is required) information. In this case, many important questions arise: how does the information processing system recognize when it is necessary to attract attention? How do psychophysiological mechanisms solve situations in which there is a conflict? Or how are motor and cognitive systems involved in information processing? What are the features of information processing in case of different modality of signals in persons with normal and hearing deprivation? It seems possible to assume that there are many ways and mechanisms that the brain can engage in processing information. In our experiment, these were instructions for the go/go or go/no-go task, the choice of response to shapes or words, and others. In this article, we consider some of the main results of our work regarding the confirmation or refutation of the hypothesis of the participation of information processing mechanisms of various complexity and modality in persons with auditory function deprivation, paying special attention to the interaction of the motor and cognitive systems of the brain.

First, based on the results of studies of the speed of the sensorimotor reaction, it was established that the functional interaction of motor and cognitive systems, as well as the speed of task performance, depend on the state of auditory function deprivation. In the go/no-go paradigm, the peculiarities of the functional interaction of the motor and cognitive systems of the brain were revealed. It was found that the time of the visual-motor reaction to words in the go/no-go paradigm in the subjects with hearing deprivation was statistically significantly longer, and the speed characteristics were lower, than those with normal hearing function ($p = 0.031$). In addition, subjects with auditory function deprivation had a higher level of functional interaction of the motor and cognitive systems that is confirmed by a higher correlation coefficient ($r = 0.66$; $p = 0.043$) than those with normal auditory function ($r = 0.38$; $p = 0.046$). This is experimental evidence that individuals with auditory function deprivation maintain lower speed characteristics of processing verbal information under the condition of a higher level of interaction of motor and cognitive systems. Therefore, it can be stated that persons with auditory function deprivation have a higher connection between the motor and cognitive systems of the brain in the task of choosing one of three verbal signals. It becomes more significant in persons with auditory function deprivation and reaches high values precisely in the task of choosing go/no-go with verbal signals when the subject needs to differentiate not only the type, but also the type of response, and also with the participation of an inhibitory signal. The obtained better results of visual reactions to words in the go/no-go paradigm of individuals with normal hearing function may be the result of coordinated cross-modal activity of the auditory and visual systems [Lyzohub et al., 2015]. Whereas in persons with auditory function deprivation, the cross-modal interaction of sensory systems during the processing of verbal information in the go/no-go paradigm requires additional involvement of integration processes from the motor system. In the case of processing of image signals, both in persons with deprivation and normal hearing function, no clear interaction of the motor and cognitive systems was found. The correlation coefficient did not reach a significant level, respectively ($r=0.23$; $p=0.073$ and $r=0.16$; $p=0.081$) between the variable series of speed characteristics of the response to figures in the go/go and go/no-go paradigm for subjects with deprivation and normal auditory function.

In addition, we have found that the functional interaction of the motor and cognitive systems of the brain and the time characteristics of the reaction speed of subjects with deprivation and normal auditory function depended on the complexity of the task. They were statistically significantly better for the go/go response than for the information processing in the go/no-go paradigm. We showed before that the process of sensorimotor information processing in go/go mode includes at least two functional systems - sensory and motor [21]. We can assume that in the go/go paradigm, motor reactions are carried out without the special involvement of analytical and synthetic activity of the cerebral cortex. This is confirmed by the absence of statistically significant differences in the values of the performance speed of the go/go task for pictural and verbal signals. If we consider that a number of researchers distinguish several important stages of functional organization for the go/go sensory-motor response, such as: signal detection, decision-making process and implementation of the motor response [28, 29], the process of processing complex verbal information in the go/no-go paradigm will include at least three functional components: sensory - the ability to perceive information, central - semantic analysis and the formation of an action program in nerve centers, as well as the implementation of a motor response [11]. It should be noted that in subjects with derivation of hearing and normal auditory function, the speed of performing tasks in the go/go paradigm was higher than in the conditions of go/no-go cognitive tasks ($p=0.026$ - 0.041). If we consider the data from literature [21] and the results shown in Table 1, it proves that in the go/no-go mode, the cognitive system is also involved in addition to the sensory and motor components of verbal information processing. We can assume that this is the ability of semantic analysis of signals and the meaning of words, switching attention, comparing information in memory, forming an action program, reacting with the right hand quickly and correctly, as well as inhibiting unnecessary reactions (no-go) [10, 15]. In addition, the conflict between the relevant and irrelevant response increased significantly in the case of the go/no-go paradigm for verbal signals, especially in individuals with derivation of auditory function. The subjects' attention was directed to the search for a conflict between a relevant (go) and an irrelevant answer (no-go). The conflict was revealed only in the tasks of response inhibition (no-go) with proactive and reactive correction of cognitive control. We can suggest that response inhibition (no-go) is associated with specific ventral neural networks (ventral attention network) [30]. It is also possible that «place neurons» and «grid neurons» selectively transmit electrical impulses and, thus, coordinate and discharge in several different nodes, which ensure the internal interaction of the system [6]. In the task of go/go to pictorial signals, the conflict, stimulus/response, reduced to a minimum reaction time for individuals with derivation and with normal auditory function did not reach a statistically significant difference (p = 0.067). A similar regularity in the go/go task was also found for the presentation of verbal signals (p = 0.075). Considering the results of this study and data from literature [8], we can assume that the functional interaction of motor and cognitive systems depended on the mode of information processing in both individuals with derivation and normal auditory function. It is higher in the go/go paradigm and lower for go/no-go tasks.

Considering the results of our study, we can assume that the functional interaction of the motor and cognitive systems of the brain, as well as the time characteristics of task performance in the go/no-go paradigm of subjects with sensory deprivation were also dependent on the modality of the signals. It should be noted that this study used visual (geometric shapes) and verbal signals (meanings of words), which were addressed to different signaling systems. It was found that for visual signals, the time characteristics in the go/no-go task were statistically significantly better than for verbal signals (p = 0.028). The fact is that the analysis of image signals is provided by the work of the first signaling system. It is known that it includes many cortical and subcortical structures, which duplicate each other to some extent and increase reliability [31, 32]. In contrast, the ontogenetic younger verbal function belongs to the second signaling system and is associated with the cortex of the large hemispheres, to a greater extent - the frontal lobes, is less stable and has a smaller neurophysiological resource [26]. Therefore, verbal functions have a higher rigidity, that is, the inability to quickly switch from the reaction to act (go) to another - to inhibit (no-go), which is associated with a low level of automation and the involvement of additional neural networks [33].

In addition, the better results of performing the task in the go/no-go paradigm for visual signals than for verbal ones can be explained from the standpoint of dominant and interference mechanisms [8, 34]. When performing the go/no-go task, it was necessary to quickly perceive visual or verbal signals, carry out their semantic analysis and quickly press the right button (go), as well as inhibit the no-go motor reaction to unnecessary signals. This created interference between two streams of information (to act or not to act) and centers of excitation and inhibition, especially in the case of performing a task with verbal signals [8]. This was evidenced by the fact that the reaction time of persons with auditory function deprivation was statistically significantly longer when performing the task in the go/no-go paradigm for words than for pictorial signals. Therefore, we can assume that in the case of verbal information processing in the go/no-go paradigm, a coordinated functional interaction of the motor and cognitive systems is established in the neural networks of subjects with hearing dysfunction. In the case of verbal signals, the speed of reaction significantly worsened in persons with auditory function deprivation, a characteristic discoordination of excitatory and inhibitory processes appeared. We can assume that there is interference in the motor and cognitive system of persons with derivation of auditory function in this case [8, 35]. Therefore, in our study, the interference effect for individuals with deprivation of auditory function depended on the modality of the signal and was more pronounced for verbal signals in the go/no-go paradigm. There was a situation where the imposition of an additional motor factor and inhibitory process on the cognitive system reduced the effectiveness of information processing. Speed characteristics of information processing in the go/no-go paradigm for pictorial and verbal signals revealed the statistically significant differences. In the case of shapes, the reaction speed was always higher than for verbal signals. In contrast, in the tests with the go/go paradigm, the task was to respond as quickly as possible by pressing the remote-control button with the right hand to the appearance of any signal without determining its modality, the type of shape or the semantic meaning of the word (motor component). It was found that there were no statistically significant differences in the speed of performing the go/go task for visual and verbal signals. This may indicate that the same basic neurophysiological mechanisms are involved in the go/go paradigm for visual and verbal information [30, 36] and neurointegration takes place in the cerebral cortex that is characterized by information synthesis and the focus of interaction for many neural networks that discharge in the same rhythm for different areas of the brain [33, 36, 37].

So, the peculiarities of cognitive information processing in the go/no-go paradigm have been established for the subjects with auditory function deprivation. Different mechanisms of cross-modal interaction in persons with deprivation and normal auditory function have been revealed. In the case of dysfunction of the sensory system, not only intra-systemic functional reorganization occurs, but also inter-system cognitive and visual-motor integration is activated in compensation. Auditory deprivation adjusts the structural and functional mechanisms of interaction of motor and cognitive systems. Such changes in the functional interaction of the motor and cognitive systems of the brain are caused by long-term deprivation and lead to a decrease in the functional reserves of the brain.

Thus, the results of the conducted research allow us to generalize the features of information processing in the go/no-go paradigm for subjects with auditory function deprivation. We have obtained features of the time of signal perception, its analysis, decision-making, and transmission to the effector. Such processing of information in persons with deprivation is characterized by specific mechanisms different from persons with normal sensory function in ensuring complex analytical and synthetic activity, the occurrence and termination of neural processes in brain networks. We can assume that the characteristics of the complexity of the task, the modality of the signals and the dysfunction of the auditory analyzer play a decisive role in information processing. It is obvious that the speed characteristics of motor and cognitive responses to verbal signals in the go/no-go paradigm were lower in persons with hearing loss, and the interaction of the motor and cognitive systems was higher than in persons with normal hearing. The better results of responses to words in the go/no-go paradigm for individuals with normal hearing function may be the result of coordinated cross-modal activity of the auditory and visual systems [21]. Whereas in persons with hearing loss, the cross-modal interaction of the visual and auditory systems was complicated, and integration processes from the motor system were additionally involved for the processing of verbal information in the go/no-go paradigm. It is obvious that in order to maintain the necessary level of information processing, the brain of people with sensory deprivation carries out a non-linear increase of the available and reserve capabilities of the cognitive system and additionally involves other subsystems. In general, constant stimulation of the cognitive function of the brain affects the formation of many synapses formed between neurons. If we assume that such connections are practically not activated in persons with auditory function deprivation, the systematic interaction of the cognitive and motor system of the brain during the processing of verbal information in the go/no-go paradigm can increase the functional capabilities of the concerned neural networks and improve sensory properties. Therefore, hearing-impaired individuals have delayed cognitive development, and it is therefore extremely important to continue trying to provide motor and cognitive stimulation. A negative consequence of such activity can be an increase in the physiological cost of the work performed. The deprivation of the auditory function significantly increases the interaction of the motor and cognitive systems of the brain, especially in the conditions of processing verbal information in the go/no-go paradigm, which hypothetically can lead to the gradual exhaustion of nervous processes and functional reserves of the body.

This study is a strong basis for further scientific research on the mechanisms of neurointegration of the motor and cognitive system in people with hearing loss and the application of this knowledge in medicine and rehabilitation.

Conclusions.

1. Various mechanisms of cross-modal interaction of the cognitive and motor system in persons with deprivation and normal auditory function have been established. In the case of deprivation of the auditory function, the visual system is activated compensatory, and the

intersystem interaction of the motor and cognitive systems is strengthened. A significantly higher manifestation of the functional interaction of motor and cognitive systems was established ($r = 0.66$; $p = 0.043$) according to the indicators of the speed of performance of tasks with verbal signals in the go/no-go paradigm in persons with derivation of the auditory function than in young men with normal hearing ($r = 0.38$; $p = 0.046$).

2. Functional interaction of the motor and cognitive systems of the brain in the subjects with deprivation and normal function of hearing, information processing depends on the modality of the signals. The time characteristics of performing tasks for visual signals were statistically significantly higher than for verbal signals ($p=0.028$) in young people with derivation of auditory function in the go/no-go paradigm.

3. We have established that the functional interaction of motor and cognitive systems, as well as the speed of task performance, depend on the choice of information processing mode. For young men with derivation of auditory function, time characteristics in the go/go mode were statistically significantly higher than in go/no-go tasks for pictorial ($p = 0.027$) and verbal ($p = 0.041$) signals. For individuals with normal hearing function, the differences in temporal characteristics in the go/no-go and go/go paradigms were for verbal ($p = 0.026$) and pictorial ($p = 0.034$) signals.

4. The results of the work and the research methodology can be used for prognostic assessment of the capabilities of human activity in conditions of complex information loads.

References

1. Rissardo, J. P., Caprara, A. L. F., & Prado, A. L. C. 2017. Projeto Semana Nacional do Cérebro: uma proposta neurocientífica. Experiência, Santa Maria, UFSM, 3(1), 86-100. doi:10.5902/2447115122193. ISSN 2447-1151.
2. Ohsumi, Y. 2016. The Nobel Prize in Physiology or Medicine 2016. Stockholm, Sweden: The Nobel Assembly at Karolinska Institute.
3. Edelman, G. M., & Gally, J. A. 2001. Degeneracy and complexity in biological systems. Proceedings of the National Academy of Sciences, 98(24), 13763-13768. doi:10.1073/pnas.231499798
4. Penrose, R., Genzel, R., & Ghez, A. 2020. The Nobel Prize in Physics 2020.
5. Zhavoronkova, L. A., Zharikova, A. V., Kushnir, E. M., Mikhalkova, A. A., & Kuptsova, S. B. 2011. Characteristics of EEG reactivity changes during the performance of dual tasks in healthy subjects (voluntary postural control and calculation). Human Physiology, 37(6), 688-699. doi: 10.1134/S0362119711060168
6. Moser, E. I., & Moser, M. B. 2011. Seeing into the future. Nature, 469(7330), 303-304.
7. Shpenkov O., Tukaev S., Zima I. 2018. Changes in brain activity in the gamma range during listening to rock music with a reduced level of low frequencies. Bulletin of Taras Shevchenko Kyiv National University. Biology. 1 (75): 27-32.
8. Lyzohub, V. S., Chernenko, N. P., Kozhemiako, T. V., Palabiyik, A. A., & Bezkopylna, S. V. 2019. Age peculiarities of interaction of motor and cognitive brain systems while processing information of different modality and complexity. Regulatory Mechanisms in Biosystems, 10(3), 288-294. doi:10.15421/021944
9. Kotsan, I. Y., Kozachuk, N. O., Kuznetsov, I. P., & Poruchynskii, A. I. 2016. Indices of coherence of EEG rhythms in the course of cognitive activity as markers of creative thinking: gender specificity. Neurophysiology, 48(4), 277-286.
10. Morenko, A. G., & Korzhik, O. V. 2016. Brain processes in women with different modal alpha-frequency through the execution of manual movements with applying of force. Ukrainian Journal of Ecology, 6(1), 326-341.
11. Lyzohub, V., Kozhemiako, T., Palabiyik, A., Khomenko, S., & Bezkopylna, S. 2020. Processing information in the go/nogo/go paradigm: interactions between cognitive function and the autonomic nervous system. Health Problems of Civilization, 14(1), 53-62. doi.org/10.5114/hpc.2020.93294.
12. Bondarenko, M. P., Bondarenko, O. V., Kravchenko, V. I., & Makarchuk, N. Y. 2016. EEG activity in dextrals and sinistrals during visual monocular/binocular perception of verbal emotionally colored information. Neurophysiology, 48, 43-53.
13. Verbruggen, F., & Logan, G. D. 2008. Automatic and controlled response inhibition: associative learning in the go/no-go and stop-signal paradigms. Journal of Experimental Psychology: General, 137(4), 649. https://doi: 10.1037/a0013170
14. Lyzohub, V., Chernenko, N., Palabiyik, A. 2019. Neurophysiological mechanisms of regulation of sensorimotor reactions of differentiation in ontogenesis. Journal of Cellular Neuroscience and Oxidative Stress. 11 (1), 805-814.
15. Doumas, M., Rapp, M. A., & Krampe, R. T. 2009. Working memory and postural control: adult age differences in potential for improvement, task priority, and dual tasking. Journals of Gerontology: Series B, 64(2), 193-201. doi:10.1093/geronb/gbp009.

16. Silsupadol, P., Shumway-Cook, A., Lugade, V., van Donkelaar, P., Chou, L. S., Mayr, U., & Woollacott, M. H. 2009. Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. Archives of physical medicine and rehabilitation, 90(3), 381-387.
17. O'Shea, S., Morris, M. E., & Iansek, R. 2002. Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks. Physical therapy, 82(9), 888-897.
18. Mohammadirad, S., Salavati, M., Takamjani, I. E., Akhbari, B., Sherafat, S., Mazaheri, M., & Negahban, H. 2012. Intra and intersession reliability of a postural control protocol in athletes with and without anterior cruciate ligament reconstruction: a dual- task paradigm. International journal of sports physical therapy, 7(6), 627.
19. Laufer, Y., Ashkenazi, T., & Josman, N. 2008. The effects of a concurrent cognitive task on the postural control of young children with and without developmental coordination disorder. Gait & posture, 27(2), 347-351.
20. Butler, J. 2013. Excitable speech: A politics of the performative. Routledge, 200.
21. Lyzogub, V. S., Makarenko, M. V., Yukhymenko, L. I., Khomenko, S. M., Koval, Yu. V., & Kozhemyako, T. V. 2015. The age dynamic of sensomotor function of people with heart deprivation. Science and Education a New Dimension. Natural and Technical Sciences, III(5), Issue: 41, 20-24.
22. Gougoux, F., Zatorre, R. J., Lassonde, M., Voss, P., & Lepore, F. 2005. A functional neuroimaging study of sound localization: visual cortex activity predicts performance in early-blind individuals. PLoS biology, 3(2), e27, 0324-0333.
23. Klinge, C., Röder, B., & Büchel, C. 2010. Increased amygdala activation to emotional auditory stimuli in the blind. Brain, 133(6), 1729-1736.
24. Yokoyama, O., Miura, N., Watanabe, J., Takemoto, A., Uchida, S., Sugiura, M., ... & Nakamura, K. 2010. Right frontopolar cortex activity correlates with reliability of retrospective rating of confidence in short-term recognition memory performance. Neuroscience research, 68(3), 199-206.
25. Voss, P., & Zatorre, R. J. 2012. Occipital cortical thickness predicts performance on pitch and musical tasks in blind individuals. Cerebral Cortex, 22(11), 2455-2465.
26. Luria, V., Krawchuk, D., Jessell, T. M., Laufer, E., & Kania, A. (2008). Specification of motor axon trajectory by ephrin-B: EphB signaling: symmetrical control of axonal patterning in the developing limb. Neuron, 60(6), 1039-1053.
27. Filimonova, N. B., Makarchuk, M. Yu., Zima, I. G., Kalnysh, V. V., Cheburkova, A. F., & Torgalo, E. O. 2019. Peculiarities of interregional interaction in the brain of soldiers with craniocerebral injuries during testing of visual working memory for complex stimuli. Herald of Cherkasy University. Series: Biological Sciences, (1), 91-102.
28. Gold, J. I., & Shadlen, M. N. 2007. The neural basis of decision making. Annual review of neuroscience, 30(1), 535-574.
29. Rozenbaum, D. A. 2010. Human movement control (2nd ed.). Boston, Elsevier Academic Press.
30. Kutsenko T. 2017. Interhemispheric transfer of information in performance of complex Stroop test involving spatial properties by right- and left-handers. Cherkasy university bulletin: biological sciences series, 1, 37-47
31. Sperry, R. W. 1980. Mind-brain interaction: Mentalism, yes; dualism, no. Neuroscience, 5(2), 195-206.
32. Maurer, C., Mergner, T., & Peterka, R. J. 2006. Multisensory control of human upright stance. Experimental brain research, 171(2), 231-250.
33. Kalnysh V. V, Shvets A. V, Maltsev O. V. 2018. Peculiarities of assessment and forecasting of spontaneous recovery of psychophysiological functions of combatants. Ukr J Occup Med, 2(55), 29-39, doi.org/10.33573/ujoh2018.02.029
34. Schubert, T., & Szameitat, A. J. 2003. Functional neuroanatomy of interference in overlapping dual tasks: an fMRI study. Cognitive Brain Research, 17(3), 733-746.
35. Hiraga, C. Y., Garry, M. I., Carson, R. G., & Summers, J. J. 2009. Dual-task interference: attentional and neurophysiological influences. Behavioural brain research, 205(1), 10-18.
36. Ivanitsky, A.M., Portnova, G.V., Martynova, O.V. [etc.]. 2013. Mapping the brain in verbal and spatial thinking. Journal of Higher Nervous Activity of human, 63(6), 677-686.
37. Korobeinikov, H., Prystupa, Ye., Korobeinikova, L., Briskin, Yu. 2013. Assessment of psychophysiological states in sport. Lviv: LDUFK, 312

Лизогуб В.С., Коваль Ю.В., Безкопильний О.О., Кожемяко Т.В.

ВЗАЄМОДІЯ МОТОРНИХ ТА КОГНІТИВНИХ СИСТЕМ МОЗКУ У ОСІБ З ДЕПРИВАЦІЄЮ СЛУХОВОЇ ФУНКЦІЇ

У осіб 17-18 років з деривацією слуху та їх однолітків з нормальною слуховою функцією досліджували особливості функціональної взаємодії моторних та когнітивних систем за умови переробки зорової інформації у парадигмі go/go та go/no-go. Когнітивне завдання у парадигмі go/no-go включало визначення модальності сигналу (форми фігури або семантичного значення слова) і вибору реакції дії (go) чи гальмування рухового акту (no-go). Моторне завдання у парадигмі go/go передбачало рухову реакцію на сигнали різної модальності.

Швидкісні характеристики зорової реакції на вербальні сигнали у парадигмі go/no-go знаходились у залежності від стану слухової функції. Час реакції на слова у осіб зі слуховою депривацією був статистично значуще більший, ніж з нормальною сенсорною функцією (p = 0,031).

У осіб з депривацією та нормальною слухової функції швидкість виконання завдань знаходились у залежності від вибору режиму обробки інформації: швидкість виконання завдання для парадигми go/go була вища у обстежуваних з депривацією (p = 0,026) та нормальною слуховою функцією (p = 0,041), ніж у парадигмі go/no-go.

У юнаків з депривацією слухової функції за показниками швидкості виконання завдання у парадигмі go/no-go на вербальні сигнали виявили вищий рівень функціональної взаємодії моторних та когнітивних систем, ніж у осіб з нормальним слухом. Коефіцієнт кореляції результатів виконання моторного і когнітивного завдання у осіб з депривацією слухової функції становив r = 0,66 (p = 0,043), а для осіб з нормальним слухом r = 0,26 (p = 0,073).

Доведено, що функціональна взаємодія моторних та когнітивних систем знаходилась у залежності від складності пред'явленої інформації, модальності сигналів та стану сенсорної функції. У разі дисфункції слуху компенсаторно активується зорова, посилюється внутрішньо- і міжсистемна функціональна взаємодія моторної та когнітивної систем. Обговорюється питання про відмінні крос-модальні механізми переробки зорової інформації у парадигмі go/no-go осіб з депривацією слуху.

Ключові слова: *деприваціяслуху, парадигма go/no-go, моторна і когнітивна системи, переробка інформації, швидкість реакції, модальність сигналу.*

Надійшла до редакції / Received: 08.11.2025
Схвалено до друку / Accepted: 16.12.2025