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Executive Functions in Individuals with Long-term Dependence on Psychoactive Substances

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Abstract

Introduction. In this paper, the aim is to identify the role of executive functions (working memory and inhibitory control) in the formation of long-term dependence on psychoactive substances (SAW). **Methods.** 95 people in the control group (not using psychoactive substances) and 146 people of the experimental group who use psychoactive substances (SAW) were examined, among them 99 people with dependence on narcotic substances of different groups and 47 people with alcohol dependence syndrome. The experience of drug and alcohol use amounted to 5-20 years. The subjects filled out a questionnaire aimed at studying the duration of psychoactive substance use and the type of these substances; they performed the tasks of the test "Progressive Matrices" by J. Raven. The paradigms of "go/go" and «go/no-go» were used to assess inhibitory control. To describe the volume of working memory and its mechanisms (proactive interference and learning), the method of O. M. Razumnikova was used. The capabilities of the SPSS-21 program package were used, and regression and factor analyses were applied. **Results.** The data obtained as a result of factor and regression analysis indicate that people with a long experience of using both narcotic substances and alcohol had difficulties in performing the tasks on scales D and E of J. Raven's Progressive Matrices, which assess the most analytical and synthetic activities. At the same time, it was shown that it is the executive functions that allow people with long-term addiction to continue social activity at a fairly stable level. Such adaptive mechanisms were a high level of learning in working memory and formed an inhibitory control. **Discussion.** Executive functions have dual functions in relation to addiction: at late provocation of addiction they have a protective function preventing the emergence of addiction, but at very early formation of addiction (up to 12 years of age), gradually forming executive functions allow to maintain a stable social state against the background of substance use.

Keywords

Psychoactive substances, alcohol, executive function, go/go and go/no-go paradigm, working memory, inhibitory control

For citation

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Introduction

Addiction is the compulsive non-medical self-reported use of narcotic substances (Wise & Robble, 2020; Arkhipova et al., 2024). Use occurs despite the negative consequences that the person taking the drugs is aware of (Leshner, 1997). Negative consequences of drug use are informed in educational institutions of different levels, in the media. However, children and adolescents (the age at which addiction is most often formed - Marenko et al., 2024) rarely see negative consequences in their immediate environment, and the result of momentary use of psychoactive substances does not appear threatening at the beginning (Yang et al., 2022). This clarification is related to the results of studies in which animals pressing a lever for a cocaine reward simultaneously received an electric shock to the legs (Deroche-Gamonet et al., 2004) or heard a sound to which they had previously developed a pain reflex (Vanderschuren & Everitt, 2004), and despite the immediate painful reinforcement, the animals selected cocaine and pressed the lever. These findings reveal a profound internal mechanism behind addiction: the initiation of use is associated with pleasant feelings, and the consequences of addiction formation are so severe that even direct pain does not contribute to the cessation of addictive behavior.

Addictive psychoactive substances (ASP) affect the brain's reward system and the extracellular oscillations of the neurotransmitter dopamine involved. Dopamine is included in the modulation of the motivation system and also controls the release of glutamate; promoting long-term cellular modifications that either enhance or inhibit the effects of glutamate, affecting the activity of the reward system that governs human behavior (Wise & Robble, 2020). In experiments on animals in which dopamine stores were artificially depleted or the dopamine system was damaged, motor activity (although there was no impairment of the motor system) and motivation, including eating, were significantly reduced: the animal could starve to death in the presence of food (Ungerstedt, 1971; Stricker & Zigmond, 1976); learning of new conditioned reflexes was impaired; and responses to predictively relevant stimuli were stopped. Responses to meaningful stimuli are critical for life: predictive stimuli lead an animal, like a human, from one reward to another, directing behavior toward survival (Bolles, 1972). Current research supports the responsibility of the reward system in shaping addictive behavior

in general and substance dependence in particular (Morie & Potenza, 2021; Ceceli et al., 2022; Barendse et al., 2024). Humans are thought to have been familiar with opiates as early as the Neolithic period (Merlin, 2003), which are exogenous ligands of morphine receptors and function to some extent as endogenous ligands of β-endorphins, enkephalins, dynorphins and nociceptin/orphanin FQ. These opioid peptides, together with their cognate peptide receptors, are widely expressed in the nervous system and, in particular, in pathways that carry information about pain (Corder et al., 2018).

The deep psychophysiological roots of addiction formation do not imply a simple solution to the problem of addiction to psychoactive substances. Therefore, there is a large body of work aimed at studying the psychological features of addictive behavior in general.

Psychological factors that increase the likelihood of a person's dependence on surfactants are a high level of impulsive planning; low level of self-direction, which, according to the psychobiological model of personality S.R. Cloninger (Cloninger, 2008) , reflects the lack of awareness of one's own capabilities and limitations; lack of purposefulness and responsibility, psychotraumatic childhood experience (Gubanova, Korzh, 2024).

One of the works described the social composition of psychoactive substance users in Russia. It was led by entrepreneurs (32%), workers were found in 23% of cases, unemployed - 20%, managers - 17%, pupils and students - 15%, housewives - 14%, servants - 11%, engineering and technical workers - 9%, mental labor workers - 8% (Aralovets, 2019). The lowest percentage of addiction among mental workers suggests that high intelligence is a protective mechanism that limits the possibility of addiction formation.

Degradation of personality, loss of social status, and even lethal outcome, especially at early onset of substance use, occur quite quickly (Aralovets, 2019). However, long-term dependence on surfactants is of particular interest with preservation of a sufficiently high social status and working capacity in the addict. This suggests the presence of some psychophysiological adaptation mechanisms that prevent the rapid destructive effect of psychoactive substances.

Currently, personality protective abilities are associated with executive functions, which are controlled by the most late in evolution and late maturing in the ontogenesis brain region, the prefrontal cortex (Nikolaeva et al., 2021; Ceceli et al., 2022). Executive functions refer to higher-order cognitive processes that play an important role in the development of self-regulation of behavior and thought operations (Roebers, 2017). These processes include monitoring, managing, controlling, and adapting lower-level information processes such as encoding, storing, and retrieving information (Paige et al., 2024). The main executive functions are inhibitory control and working memory (Ede & Nobre, 2023).

Working memory is memory for intermediate stages of some process (Velichkovsky, 2016), which involves at least two mechanisms: proactive interference (Anderson & Hulbert, 2021) and learning during reproduction (Streb et al. , 2016). Although the first mechanism impairs subsequent memorization, the second mechanism ensures its retention despite the presence of distractors (Razumnikova & Nikolaeva, 2019).

The role of executive functions in the formation of addiction is actively researched. Hildebrandt et al. (2021) found 359 articles on pubMed and Web of Science platforms in 2020 alone that in one way or another examined the relationship between inhibitory control and substance dependence. After analyzing the papers in depth, they noted that many studies support this relationship, but there are also a fair number of papers that are inconsistent with this conclusion. The authors found no explanation for this contradiction and noted the urgent need for further research.

At the same time, the authors emphasize both the diversity of approaches to assess executive function and the diversity of evaluated samples in the studies.

We thought it would be meaningful to examine people who have been using narcotic substances for quite a long time and have retained their jobs, sometimes in fairly well-paid prestigious jobs, because rapid degradation of personality has been described many times. The question arises: what can keep a person from rapid degradation while maintaining dependence on psychoactive substances?

We suggested that it is the executive functions that may be the protective factors preventing a person from becoming addicted at an early age, and it is the executive functions that may become an adaptive mechanism for the stability of addictive behavior; but if addiction occurred before the executive functions were formed, their further formation may lead to a situation of long-term substance use,

Purpose of the study: to identify the characteristics of executive functions in long-term (5-20 years) users of psychoactive substances (PAS).

Methods

Participants

The study was carried out in various **Alcoholics Anonymous and Narcotics Anonymous** societies.

People who had undergone rehabilitation in one in the hospitals of St. Petersburg and completed the necessary medications were selected for the study.

A total of 241 individuals were examined.

The **control** group included 95 people (volunteers who responded to the call for the study on the Internet) aged 34.7±9.4 years (of whom 48% were women and 52% were men) who did not use psychoactive substances. To ensure homogeneity of the sample, study participants were selected into the control group according to the age of the study participants who were substance users.

The experimental group consisted of 146 people aged 35.6 ± 7.8 years (39% women and 61% men) with a long (5 to 20 years) experience of drug and alcohol use. Among them:

- 47 people addicted to alcohol;
- 99 from drugs;
- 4 people in the sample had their first use at age 6 (2 first-time drug users, 2 first-time alcohol users).

The individuals studied used various surfactants, often in combination, but the impact of these differences was not evaluated in this study, including 25 opioid users, 31 stimulant users, and 43 multiple users. When comparing the characteristics of executive functions between the groups in the analysis of variance, no differences were found between the groups. The criterion for inclusion in the experimental group was the ICD-10 diagnosis of "addiction syndrome" made by a hospital physician.

Table 1

Distribution of participants by duration of substance use, M±SD

Group	Duration of use, years
All surfactant group	17,4±8,1
Subgroups	
Drugs	16,3±7,6
Alcohol	19,8±8,8
Subgroups of drug users	
Opioids	20,3±5,4
Stimulants	14,2±8,0
Several drugs	15,3±8,0

Table 1 shows that the average duration of substance use in all groups was 14–20 years, which confirms the long-term nature of addiction.

As can be seen in Table 2, the early onset of drug use is correlated with the age of 6–12 years and the later onset after the age of 25 years.

Table 2
Distribution of participants with different ages of initiation of drug use by duration of drug use, M±SD

Age of onset of use, years	Age of use mean value, years	Number of participants
6 – 12	21,7	10
13 – 17	17,2	56
18 – 20	13,4	13
21 – 25	15,1	13
старше 25	8,1	7

Table 3
Distribution of participants with different ages of alcohol initiation by duration of alcohol use, M±SD

Age of onset of use, years	Age of use, mean value, years	Number of participants
6 – 12	21,0	6
13 – 17	23,9	18
18 – 20	19,6	10
21 -25	19,7	6
старше 25	8,7	7

The distribution of participants who use alcohol by age of onset and duration of use is consistent with that of participants who use drugs. The most likely time for initiation of substance use is in adolescence.

It should be emphasized that the sample included people who use substances but nevertheless maintain their social status. Table 4 shows the distribution of study participants by education level.

Table 4

Comparison of the the educational level in study participants of different groups and subgroups, N

Group	Academic degree	Higher	Secondary specialty	Average
control	2	60	22	11
all surfactant group	2	36*	63*	45*
Subgroups				
drugs	1	20*	46*	36*
alcohol	1	16*	19*	11*
Subgroup of drug users				
opioids	0	4*	14**	7*
stimulants	1	8*	13	9
multiple surfactants	0	8*	17*	18

Note: ** - difference between the participants of the indicators of the control group and the indicators of the study participants using surfactant, with significance level p <0.05, ** - p ≤ 0.01 (Mann-Whitney test).*

As can be seen from Table 4, higher education is more common in the group of nonusers, while people with specialized secondary education predominate among substance users. However, science candidates are equally common in all groups. This emphasizes the fact that there is no social degradation among study participants. All of them had a permanent job.

Informed consents were obtained from all subjects to participate in the study.

Methodic

All subjects completed a questionnaire aimed at examining the duration of substance use.

The studies were conducted face-to-face and individually.

Among executive functions, inhibitory control and working memory were chosen because there are currently reliable tools to study them (Reichl et al., 2023). To assess inhibitory control, the "go/go" and "go/no-go" paradigms were used (Razumnikova and Nikolaeva, 2021). In the first case, the subject had to respond by pressing a button on the computer keyboard when any stimulus appeared on the screen, while in the second case there was an instruction not to respond to certain stimuli, the response to which had already been developed in the first case (Krivoshchekov et al., 2022).

In a technique aimed at assessing working memory, the same set of stimuli was presented in three series in different sequences. They were required to select a stimulus on the screen that had not been selected before. If an error was made, the next series was started. The number of correctly memorized stimuli was counted. Interference was assessed by a decrease in the number of reproduced stimuli in the subsequent series, while learning was assessed, on the contrary, by an increase in the number of memorized stimuli in the next series (Razumnikova, Nikolaeva, 2019).

In addition, J. Raven's (2002) Progressive Matrices test was used to assess nonverbal intelligence. This test was used to show that the intelligence of all participants is within the normal range, and therefore the differences in executive functions between substance dependent and nondependent participants are not determined by reduced intelligence as a consequence of substance use.

Data processing

All data were entered into a table and processed using the SPSS-21 program package. Data were assessed for normality using the Kolmogorov-Smirnov test, and factor and regression analyses were performed.

Ethical review

The work complies with the ethical standards of the Declaration of Helsinki (minutes of the meeting of the local ethics committee of the neurological clinic "Prognosis" No. 10 of 13.11.2020).

Results

After entering all results, a qualitative analysis was performed that included comparison of the mean values of all the parameters studied. It did not reveal significant differences in the level of executive functions between the control and the two experimental groups. The absence of such differences was due to the large variation of the data in the groups composed of alcohol and drug addicts.

It should be emphasized that all subjects had intelligence levels within the normal range, although differences were found for individual scales. These differences were further revealed in other types of analysis presented below.

The results of the factor analysis are presented in Tables 5 and 6. After excluding variables that received a small weight (less than 0.4), a four-factor solution with a Kaiser-Meyer-Olkin sampling adequacy of 0.611 was obtained, which allowed us to accept this variant for consideration (the percentage of explained variance was 64.4%). All of this can be found in Table 5.

Table 5

Kaiser-Meyer Olkin criterion and Bartlett's criterion

Kaiser-Meyer-Olkin adequacy criterion		0,611
Bartlett's sphericity test	Approximated chi-squared	375,445
	Significance level	0,000

Table 6 summarizes the components of factor analysis.

Table 6

Rotated component matrix

Variables	Components		
	1	2	3
Attitude towards addiction: 0 - none, 1 - alcohol, 2 - drugs	0,857	-0,255	0,016
Age of first use	0,845	-0,284	0,053

Variables	Components		
	1	2	3
Number of items played back in the first playback in the working memory	-0,525	-0,050	-0,002
Number of items played back in the second playback in the working memory	-0,067	0,827	0,057
Number of items played back in the third playback in the working memory	-0,219	0,633	-0,105
Number of errors in go/no-go series	0,200	0,207	0,826
Number of passes in go/no-go series	-0,176	-0,351	0,749

Extraction method: principal component method

Rotation method: Varimax with Kaiser normalization

The rotation occurred in 5 iterations

According to Table 6, the first factor (percentage of explained variance 26.4%) included, with high weights, the attitude toward the group of alcohol and substance dependents, the age of first use of alcohol or a substance, and the amount of first recall in working memory. These results suggest that the lower the age of first use, the lower the volume of first recall in the working memory test, the higher the likelihood of being in the alcohol or substance-dependent group.

The second component (20.0% of the explained variance) includes the other two reproductions in working memory. The third factor (18.0% of explained variance) includes both parameters related to inhibitory control.

Our data testify to the already known phenomenon, according to which the age of first use plays a major role in the formation of a person's dependence on alcohol or drugs. It is important that first reproduction in working memory is impaired. However,

subsequent reproductions in working memory do not distinguish between groups of addicts and independents of certain substances. This means that in addicts the mechanism of learning in working memory is active, which makes it possible to compensate for the first failure in reproduction and compensate for the lack of involvement in the task.

Next, a linear stepwise regression analysis with all included variables is presented, where the dependent variable was the group of subjects using alcohol or drugs, is presented next (Table 7).

Table 7
Influence of independent variables on the dependent variable "group of persons using alcohol"

Independent variables		R^2	Durbin-Watson criterion
Age of first use of alcohol E scale of the J. Raven test, errors in the go/no-go test, The amount of the first playback in working memory	R=0,908 p=0,000	0,8235	1,925

Regression analysis produced a model in which four parameters predetermine whether a person falls into the long-term alcohol dependence: the age of first alcohol use (β=0.679), the number of scores on the J scale of the J. Raven test (β=-0.202), the number of errors in the go / no-go series (β=-0.101), and the volume of first playback in working memory (β=-0.155). This model explains 83.3% of the variation in the dependent variable "group of people who drink alcohol" and is highly significant. It can be used because the Durbin-Watson criterion is 1.925. The beta coefficient is negative for all parameters except the duration of alcohol use. The probability of becoming an alcoholic with a long history of drinking is determined by the early age of onset of drinking, a decrease in the success rate of one of the most difficult series in the J. Raven test, which requires effective analytical activity and deterioration of executive functions (inhibitory control and working memory). It should be emphasized that inhibitory control has the minimum weight in relation to another component of executive functions, working memory, while early onset of addiction has the maximum weight among all parameters.

Table 8 presents a model of the factors that predetermine the likelihood that an individual is a substance-dependent person.

Table 8
Effect of independent variables on the dependent variable "group of drug users"

Independent variables		R^2	Durbin-Watson criterion
	R=0,923		
Duration of substance use,			
E D scale of the J. Raven test,		0,852	1,749
errors in the test	p=0,000		

The model obtained in the regression analysis explains 85.7% of the variation in the dependent variable. In it, the probability of falling into the group of drug users is also determined by the duration of surfactant use (β=0.842), the level of task performance on scales E (β=-0.088) and D (β=-0.073), the number of errors in the test evaluating inhibitory control (β=-0.077). The beta coefficient is negative for all values except the duration of use. Consequently, the lower the results of the D and E scales of the J. Raven's test, the more the inhibitory control process is disturbed, the more likely a person falls into the group of substance dependents. However, it should be emphasized that the maximum weight in this model belongs to the duration of the use of substances.

Discussion

The need to find mechanisms to counteract the emergence of addiction is extremely important today (Arkhipova, 2024; Gubanova, Korzh, 2024). The specificity of the sample under study consists in the fact that it includes people who have been addicted to surfactants at different times, but at the same time have been functioning in society for a long time (from 5 years to 20 years) with retention of a job. Many people addicted to surfactants degrade rather quickly and often die quite early (Aralovets, 2019; Nikolaeva et al., 2021). All this suggests that these people have a compensatory mechanism that allows them to resist degradation.

Our data are fully consistent with the numerous previous findings that the earlier a person starts surfactant use, the more likely he or she is to fall into the group of addicts (Marsenko et al., 2024; Roschina, Belova, 2024; Formánek et al., 2022). At the same time, the literature presents extremely contradictory data regarding the level of intelligence

and efficiency of executive functions (Hildebrandt et al., 2021; Morie, Potenza, 2021; Reichl et al., 2023).

We have shown that people with long-term substance use have significantly reduced more complex thinking processes, i.e. the ability to analytical and synthetic activity (scales D and E of the J. Raven's test) against the background of no pronounced change in intelligence. These people can perform quite simple intellectual operations, but problems with synthesis and analysis become a prognostic factor of belonging to the group of addicts.

We did not see any pronounced changes in inhibitory control in the group as a whole, which can be explained by a compensatory mechanism that consists of slower performance of all tasks by the substance-dependent participants of the study compared to those who were not dependent. Moreover, it is possible to assume that the absence of a pronounced decrease in inhibitory control allows these subjects to use alcohol and surfactant use, thus preserving their social status.

It is known that working memory is more affected in alcoholism (Peshkovskaya, 2023; Powell et al., 2024), while in drug use, intellectual impairments are more pronounced (Mistler et al., 2021), which is confirmed by the results of the regression analysis. Addicts are quite easy to cope with simple intellectual tasks, so they can stay for a long time in jobs where routine identical daily activities take place. The addicts in our sample do have a reduced first replay, but later, based on the learning mechanism in working memory, they show consistently high volume in the second and third replays, reflecting the activation of a learning mechanism (Streb et al., 2016) that counteracts proactive interference (Anderson and Hulbert, 2021). Thus, it is the ability to overcome the difficulties that arise in the process of memorizing information that allows these people to exist in society quite effectively while using surfactants.

Perhaps, in the case of long-term addiction to psychoactive substances (in our sample there were such people, and it is known that most addicted people die quite early - Pepe et al., 2023), even with a decrease in the functioning of intellectual operations of synthesis and analysis, a more dosed use of surfactants is developed due to adaptation (Mistler et al., 2021), the mechanisms of which are learning in working memory, which allows to overcome the forgetting mechanism, and some level of inhibitory control, which is formed sufficiently to limit the use of psychoactive substances (Mistler et al., 2021).

These findings extend the theoretical constructs of S.R. Cloninger (Cloninger, 2008), who suggested that substance use is associated with decreased awareness of one's behavior. They show how behaviorally aware individuals can continue self-destructive behaviors for many years, relying on cognitive control mechanisms.

Conclusion

Our data show that people with a long experience (up to 20 years and more) of substance use have lower scores on the most difficult scales of the J. Raven test of nonverbal intelligence - scales D and E. At the same time, they develop compensatory mechanisms that allow them to maintain a stable social position for a long time. At the same time, they develop compensatory mechanisms that allow them to maintain a stable social position for a long time. Such mechanisms are formed as inhibitory control and learning mechanism in working memory. Consequently, executive functions in the absence of early provocation of substance use will be a protective factor for the initiation of substance use. But if provocation occurs, then in the case of gradual addiction, the emerging executive functions can become an adaptive mechanism that keeps addicts in a stable social status for a long time.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.