NEUROPSYCHOLINGUISTIC LINKS BETWEEN PROCRASTINATION AND PROSPECTIVE MEMORY

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Abstract. The research objective is to examine the brain activity of individuals with different levels of procrastination. The study applies EEG data analysis with different levels of linguistic stimuli complexity (letter and semantic word), allowing to change the cognitive load and register the electrical activity of the cerebral cortex while performing tasks with two different stimuli: perceptual and semantic. We registered the electrical activity of the cerebral cortex in 20 individuals (18 females, 2 males) in the shielding lightproof testing room of the Laboratory of Age

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Neurophysiology at Lesya Ukrainka Volyn National University. This technique analyzes the dynamics of cortical electrogenesis identifies general patterns of local and spatial synchronization of biopotentials of the cerebral cortex. The findings indicate that the dynamics of cortical electrogenesis of prospective memory depends on linguistic stimuli complexity in procrastinators, associated with increased energy expenditure. Furthermore, the largest number of statistically significant intergroup differences in subjects with different levels of procrastination was found in the beta range of EEG, indicating the rhythm of activity. On the one hand, this rhythm of activity is dependent on the optimization of problem-solving. On the other, the increase in its power reflects cortical excitation and selective inhibition. Evidence consistently suggests that the complexity of the linguistic task increases the interaction of brain macrostructures in the anterior associative zone (fronto-central leads) in students with dilatory behaviour. In contrast, subjects without dilatory behaviour demonstrate only changes in spatial synchronization modulated according to the linguistic stimuli complexity.

Keywords: *procrastination, prospective memory, electrical activity of the cerebral cortex, linguistic stimuli complexity.*

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Анотація. Метою дослідження є вивчення мозкової активності людей з різним рівнем прокрастинації. У дослідженні проведено аналіз даних ЕЕГ за стимуляції мозку вербальними стимулами різного рівня складності (буквеного ситимула та смислового слова), що дозволяє змінювати когнітивне навантаження та реєструвати електричну активність кори головного мозку при виконанні завдань із двома різними стимулами: перцептивним та семантичним. Нами проведена реєстрація електричної активності кори головного мозку у 20 осіб (18 чоловіків, 2 жінки) в екранному світло- та звукоізольованому кабінеті лабораторії вікової нейрофізіології Волинського національного університету імені Лесі Українки. Ця методика дає можливість проаналізувати динаміку коркового електрогенезу, виявляє загальні закономірності локальної та просторової синхронізації біопотенціалів кори головного мозку. Отримані дані свідчать про те, що динаміка коркового електрогенезу при подачі стимулів на проспективну пам'ять залежить від складності мовних стимулів у прокрастинаторів, які пов'язані із збільшенням енергетичних витрат. Крім того найбільшу кількість статистично значущих міжгрупових відмінностей у суб'єктів із різними рівнями прокрастинації було виявлено в бета-діапазоні ЕЕГ. З одного боку, цей ритм діяльності залежить від оптимізації вирішення проблем, з іншого боку, збільшення його потужності відображає кортикальне збудження і вибіркове гальмування. Отримані дані також свідчать про те, що складність лінгвістичного завдання посилює взаємодію макроструктур мозку в передній асоціативній зоні (фронто-центральні відведення) у студентів зі схильністю до відтермінування. Навпаки, суб'єкти без прокрастинації демонструють лише зміни просторової синхронізації, модульовані відповідно до складності лінгвістичних стимулів.

Ключові слова: *прокрастинація, проспективна пам'ять, електрична активність кори головного мозку, складність мовних стимулів.*

Introduction

The individual ability to discipline and self-organise determines success and effectiveness in the modern social environment. However, even if the individual has all the necessary resources, reluctance to use them on time in situations requiring immediate decision-making and specific actions can negatively affect the outcome. In this light phenomenon of procrastination attracts attention in the recent research of individual efficacy.

The current studies examine procrastination extensively applying the psychometric approach to the delayed behaviour. However, no previous study has investigated procrastination from the perspective of the integrated model, postulating the ideas of the biological substrate of procrastination. Previous research has established that the behavioral procrastination was positively correlated with the regional activity of the ventromedial prefrontal cortex and the parahippocampal cortex, while negatively correlated with that of the anterior prefrontal cortex (Zhang, Wang, & Feng, 2016). Particular attention in this context deserves visualisation methods of brain processes to identify neural structures associated with procrastination (Wong et al., 2018; Wu et al., 2016). Most researchers investigating brain and procrastination have utilized fMRI. The present study applies encephalography (EEG) to examine the neural nature of procrastination.

Concerning the development of the paradigm of modern EEG research, we assume the relationship of procrastination with a separate memory subsystem, which stores information about life events and intentions for future actions. This type of memory has been called prospective memory instead of classical retrospective memory (Ericson, 2017).

In developing this study, we suggest different tasks combining two types of linguistic stimuli: task giving an access to working memory and task activating prospective memory. Two tasks have been introduced to the subjects simultaneously. Moreover, stimuli, activating prospective memory, included perceptual stimulus (Raskin et al., 2011) and semantic stimulus (West, 2008; Crystal & Wilson, 2015). The current study aims to examine the brain activity of individuals with different levels of procrastination. We apply EEG data analysis with different levels of linguistic stimuli complexity (letter and semantic word), allowing to change the cognitive load and register the electrical activity of the cerebral cortex while performing tasks with two different stimuli: perceptual and semantic.

Methods

The study examines brain responses to prospective stimuli in individuals with different levels of procrastination and includes two stages: psychological and neurophysiological. At the first stage, we selected 20 individuals (18 men and 2 women) and divided them in two equal groups applying a questionnaire for procrastination assessment (Zhuravlova & Zhuravlov, 2018). Table 1 illustrates descriptive statistics of the sample.

At the next stage, the electrical activity of the cerebral cortex was registered in a shielded room with the sound and light isolated in the Laboratory of Age Neurophysiology at Lesya Ukrainka Volyn National University (Ukraine). This technique analyses the dynamics of cortical electrogenesis and identifies general patterns of local and spatial synchronisation of biopotentials of the cerebral cortex.

The electrical activity of the cerebral cortex was recorded monopolar using the hardware and software complex "Neurocom", developed by the Scientific and Technical Center for Radio-Electronic Medical Devices and Technologies "KHAI-Medica" of Zhukovsky National Aerospace University “Kharkiv Aviation Institute” (Ukraine). The subjects were sitting at a distance of 1.5 m from the computer monitor demonstrating different stimulus material.

The electrodes were placed according to the international system of 10/20% in 21 symmetrical points of the left and right hemispheres of the brain. The experiment applies referent ear electrodes A1 and A2, and additional referent electrodes N and Ref. During the Fourier transform, the epoch of analysis was 500 ms. Analog signal sampling frequency – 2 ms; input resistance for in-phase signal – more than 100 Mohm. High-frequency filters are set to 50 Hz, low – 0.1 Hz – limits of possible relative error when measuring voltage and time intervals of electroencephalographic signals – ± 5%.

The study applies ICA analysis to screen EEG artefacts. Subsequently, the ISA components were filtered with the artefact signal and composition of non-artefact ISA, resulting in general patterns of EEG. In the cases that artefact activity could not be filtered by ISA treatment, artefact EEG segments were manually excised from the EEG.

The study registered electrical activity of the cerebral cortex while performing test tasks of two types, introducing perceptual and semantic stimuli.

1. Prospective memory test using a perceptual stimulus. We instructed the subject to indicate the presence/absence of a semantic pair by pressing the "left" key in case of a semantic pair or "right" in its absence (a task for the use of working memory). If a word starts with a capital letter appearing on the screen, the subject must press the "down" key (prospective memory task). After pressing the appropriate key, the subject received feedback on the correctness of choice. The total duration of the test was 15 min and involved sorting 200 words, of which 20 were with capital letters. To avoid an automatic response by the subjects, the interval of presentation of stimuli ranged from 1 to 1.5 s, the duration of the demonstration of words – 2 s.

2. Test for prospective memory using a semantic stimulus. We asked the subjects to indicate the presence/absence of a semantic pair with the demonstrated word by pressing the "left" key in the case of semantic pair or "right" in its absence (a task for the use of working memory). If a word denoting animal appeared on the screen, the subject had to press the "down" key (prospective memory task). After pressing the appropriate key, the subject received feedback on the correctness of choice. The total duration of the test was 15 min and involved the sorting of 200 words, 20 of which contained the names of animals. Although to avoid an automatic response by the subjects, the interval of presentation of stimuli ranged from 1 to 1.5 s, the duration of the demonstration of words was 2 s.

The stimulus material for the EEG study was developed in the open-source software package PsychoPy (version 1.90.3). Statistical processing of experimental data involved nonparametric Wilcoxon criteria.

Results and Discussion

The research dataset has been uploaded to Mendeley Data Repository (Zhuravlov & Zhuravlova, 2022).

Table 1
Descriptive Information for the Individuals with Different Procrastination Levels (n=10) – high (n=10) – low level

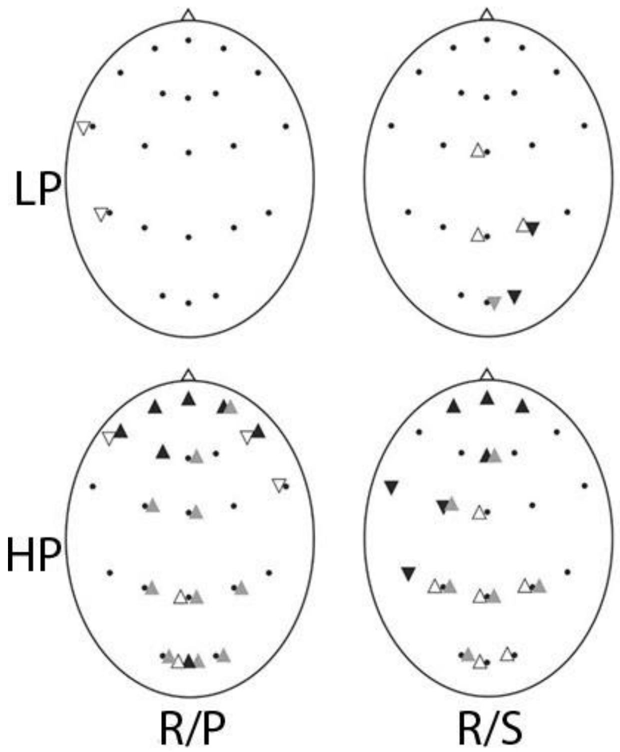
	High level of procrastination		Low level of procrastination	
	Frequency	Percentage	Frequency	Percentage
Gender				
Female/male	9/1	90.0/10.0	9/1	90.0/10.0
Marital status				
Single	7	70.0	9	90.0
Married	2	20.0	1	10.0
Divorced	1	10.0	0	.0
Occupational status				
Full-time worked	1	10.0	0	.0
Part-time worked	2	20.0	4	40.0
Student	7	70.0	6	60.0
	Mean (SD)	Min-Max		
Age	21.5 (5.33)	17-35		

The study of the cerebral cortex activation according to the spectral power of EEG revealed several specific electrogenesis in individuals with high procrastination. Furthermore, in all frequency bands of electrical activity, its dynamics was characterised by more generalised changes (see Fig. 1).

The findings show no changes in cortical electrogenesis of the group with low procrastination while performing perceptual (simple cognitive tasks). However, the study reveals significant differences in this group in two conditions: performing perceptual tasks and rest with open eyes covering only the left temporal structures (Fig. 1). Performing more complicated cognitive tasks with semantic stimuli is associated with local changes, covering all EEG bands. The findings indicate changes in alpha activity in Cz, Pz, and P4 sites and express increased values. In the remaining EEG bands, the changes relate only to the central occipital zone (theta band) and the right occipital and parietal areas (beta band) (Fig. 1).

Figure 1

Significant Changes in the Spectral Power of the Basic EEG Rhythms When Comparing Test Situations of Rest for Individuals with Low (LP) and High (HP) Procrastination.



Note. An up arrow at the location of the corresponding zone indicates an increase in power. A down arrow indicates a decrease. The colours indicate white – alpha rhythm, black – beta rhythm, grey – theta rhythm.

The letters denote P – prospective memory test (perceptual stimulus); S – prospective memory test (semantic stimulus).

In the group with high procrastination, the transition from rest to prospective memory test was accompanied by a broad adjustment of the spectral power of brain structures, including adjustment of the activity of all EEG frequency bands. The use of verbal stimuli led to increased spectral power in the alpha band in the central, all parietal and occipital areas. In contrast, perceptual (letter) stimulus increased spectral power in the central parietal and temporal areas combined with a decrease in both lateral frontal areas and right anterior temporal. Such changes indicate an increase in energy expenditure when performing a mental task in individuals with high levels of procrastination.

The largest number of statistically significant intergroup differences represent the beta band of the EEG, which relates to the rhythm of activity. On the one hand, this band depends on the task optimisation and, on the other, on the increased power of reflection of cortical excitation. Performing a prospective semantic test compared to the condition of rest is characterised by activation of all anterior and central posterior zones. At the same time, performing the perceptual task increases the spectral power of beta-rhythm covering almost all frontal areas and central occipital. One unexpected finding is the decrease in beta activity in the temporal and central areas of the left hemisphere during the test for semantic prospective memory, which is not observed in perceptual stimulation (Fig. 1).

Changes in the spectral power of the theta EEG band are mainly related to the central structures of the cortex. They are virtually indistinguishable in both prospective memory tests in individuals with high levels of procrastination.

The findings of cortical electrogenesis while performing tests for prospective memory using different stimuli indicate exciting effects related to the response to two different stimulations, perceptual and semantic.

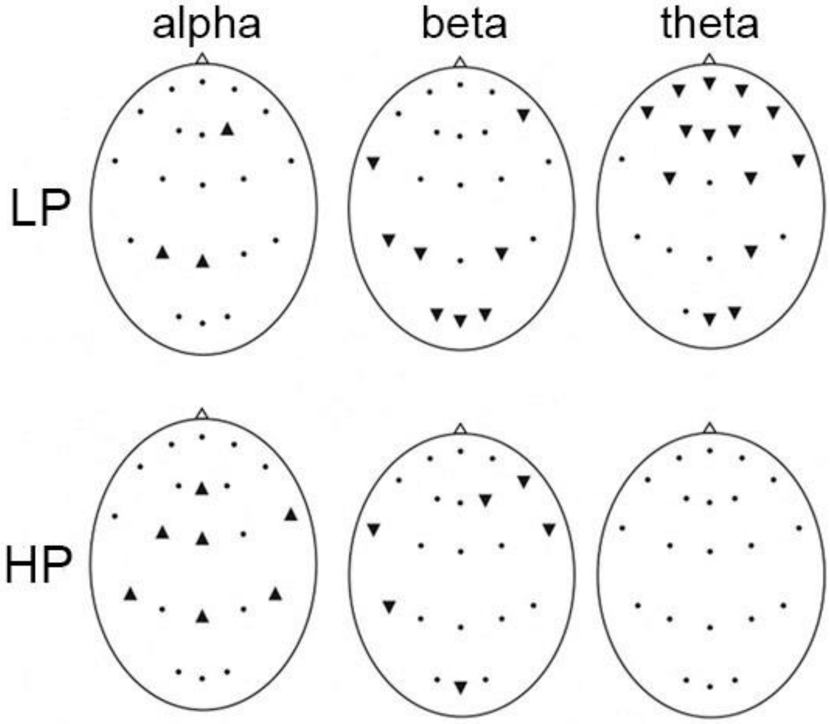
Comparison of the spectral power of the cerebral cortex during prospective memory tests with perceptual and semantic stimuli showed that in the group with low procrastination, the greatest number of statistically significant differences was found in the theta band of EEG. In contrast, in the group with high procrastination, there are no differences at all (Fig. 2). The findings also demonstrate the lack of reorganisation of theta activity in the group with high procrastination. Previous research shows that organising and maintaining cortical activity correlates with brain energy expenditure during cognitive tasks and increases with increasing complexity and duration work on them (Gevins & Smith, 2000). Thus, preserving generalised activation of the theta band of EEG in procrastinators may indicate a more significant energy expenditure of the brain to perform tasks by maintaining the appropriate level of attention during mental activity.

Comparative analysis of the dynamics of electrogenesis of cortical zones in tests for prospective memory with different types of stimulation revealed peculiarities in both groups of subjects and the beta band of the EEG. In the group of individuals with low procrastination, there is a statistically significant ($p < .05$) decrease in the spectral power of the beta band of activity in the right lateral frontal zone, left anterior and posterior and symmetrical parietal and occipital areas, including the central occipital during the transition from perceptual to semantic stimulus material (Fig. 2). In the group with high procrastination, the the electrical activity of the cerebral cortex under different stimulations during the test for prospective memory also contain a wide range of changes. A significant decrease in beta-rhythm ($p < .05$) occurs more in the right hemisphere and localises in the right frontal temporal and left posterior temporal areas and the central occipital area.

Comparison of the electrical activity of the brain when performing tasks on prospective memory (semantic and perceptual stimuli) in the alpha band of the EEG showed that individuals with low procrastination demonstrate a statistically significant ($p < .05$) increase in the level of spectral power of alpha activity in the right posterior frontal, left and central parietal locations (Fig. 2). For individuals with high procrastination, two different test situations represent broader changes in the cerebral cortex's electrogenesis, increasing the right temporal, left central, and both parietal areas of the cerebral cortex, as well as in the central zone of the cortex, parietal and occipital locations (Fig. 2).

The study does not find out the intergroup difference of values during the prospective memory task with semantic stimuli, despite significant differences in the topographic distribution of the dynamics of electrical activity.

Figure 2
Significant Changes in the Spectral Power of the Basic EEG Rhythms When Comparing Tests for Prospective Memory Using Perceptual and Semantic Stimuli in Individuals with Low (LP) and High (HP) Procrastination.



Note. An up arrow at the location of the corresponding zone indicates an increase in power, a down arrow indicates a decrease.

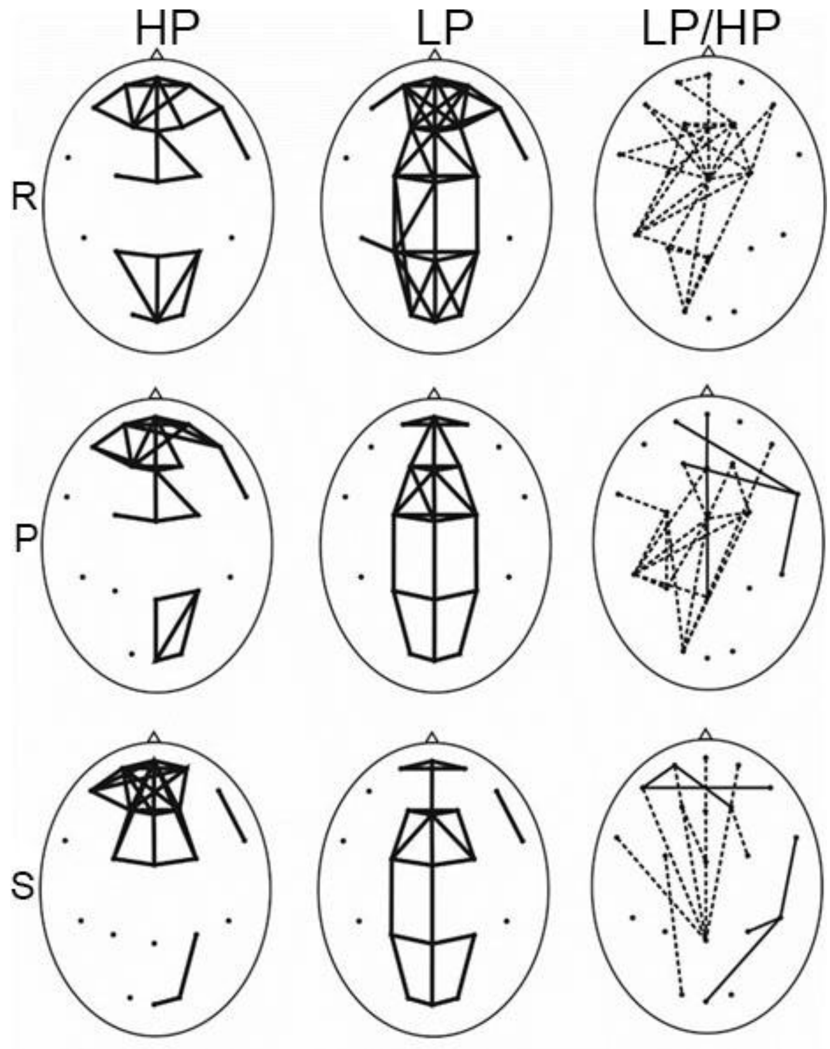
Spatial synchronisation of the bioelectrical activity of the cerebral cortex indicates the coherence of its parts and the level of their interaction in the cognitive activity. Individuals with different levels of procrastination in the condition of rest demonstrate peculiarities of spatial synchronisation.

An experimental study showed that in the group with high procrastination when performing the tasks both with perceptual and semantic stimuli, there is an increase of interaction of brain macrostructures in the anterior associative zone (fronto-central zones). At the same time, in individuals with low procrastination, changes in spatial synchronisation depend on the type of task. Analysis of statistically significant intergroup differences in the level of spatial synchronisation of cortical zones showed that in the condition of rest, higher rates were observed in the group of non-procrastinators. In comparison, the transition to the test for prospective memory group with high procrastination demonstrate higher rates (Fig. 3).

Recent findings in neurophysiology suggest that cognitive activity vs condition of low cognitive performance provides spatio-temporal dynamics of brain activity in the entire frequency spectrum of oscillations between symmetrical zones of the cerebral cortex and anteroposterior brain (Berdnikov, 2017). Researchers, in particular, emphasise that different cognitive activities relate to reliable cortico-activation structures. Thus, the performance of computational operations is mainly associated with the localisation of brain activity in the left frontal area and the close interaction of the temporal and central parietal structures of both hemispheres. Performing spatial tasks relates to developing foci of activity in the frontal area of the right hemisphere and increasing the activity of parietal and occipital zones of the same hemisphere. Verbal-logical tasks increase the activity of the left frontal hemisphere, including the Broca's area. In addition, the importance of interhemispheric coherence of rhythms in the frontal zones relates to a reliable decrease in depressive disorders and reduced performance (Varlamov & Strelec, 2013).

Figure 3

Spatial Synchronisation of the Biopotentials of the Cortex of the Large Hemispheres in the Conditions of Rest and the Performance of Cognitive Tasks in Individuals with Different Levels of Procrastination



Note. LP – individuals with low procrastination, HP – individuals with high procrastination, LP / HP – statistically significant ($p < 0.05$) differences between the group of individuals with high and low procrastination (solid lines indicate statistically significantly higher values in the group with a high level of procrastination, dotted – statistically significantly higher values in the group with a low level of procrastination).

Thus, the analysis of the dynamics of the electrical activity of the cerebral cortex revealed several specific features for individuals with high procrastination. The most significant number of differences in absolute spectral power was observed in the EEG beta band, where statistically significantly lower values are found in the condition of rest. The number of differences increases in performing the tasks with two different stimuli: perceptual and semantic. The experimental groups do not demonstrate significant differences in theta band of the brain's electrical activity. However, the spatial distribution and activation/deactivation of brain structures show that procrastinators are characterised by changes in spectral power in all EEG frequency bands during the transition from rest conditions to cognitive activity and during performing tasks with different stimuli.

Conclusions

Comparative analysis of the dynamics of electrogenesis of cortical zones in performing a test for prospective memory with two linguistic stimuli of different levels of complexity revealed peculiarities in individuals with different levels of procrastination. According to the spectral power of the EEG, individuals with high procrastination demonstrate an increase in values in all frequency bands of electrical activity. Such increase is associated with the level of energy expenditure during cognitive tasks in individuals with a high level of procrastination.

The study revealed statistically significant intergroup differences in the beta band of EEG, which relates to the rhythm of activity, optimisation of problem-solving, and power increase of cortical excitation and selective inhibition.

Spatial synchronisation of the bioelectrical activity of the cerebral cortex indicates the coherence of its parts and shows the degree of their interaction during cognitive activity. Individuals with high procrastination demonstrate increased interaction of brain macrostructures in the anterior associative zone (fronto-central locations) while performing linguistic tasks. The study revealed statistically significant intergroup differences in spatial synchronisation of cortical zones in individuals with low procrastination, who demonstrate higher rates in the condition of rest. In contrast, individuals with high procrastination show higher rates during the transition to the more complex stimulus.

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