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MONITORING THE LOADING OF EXECUTIVE FUNCTIONS WHILE INSIGHT PROBLEM SOLVING USING A SINGLE TONE PARADIGM

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Мониторинг загрузки управляющих функций в решении инсайтных задач с использованием парадигмы сингл-тон

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Abstract

Abandoning the strategy of consciously searching for a solution can be an insight mechanism. A number of studies have shown that control is important for both insightful and non-insightful tasks. From this it follows that the control has different functions. Insight occurs in several stages, at which the role of control is different. In the beginning, the task is solved as non-insightful and control is needed for intelligence. This continues until an impasse in the solution is reached. Next, intuitive processes come to the first role, and the role of control is decreasing. To study the dynamics of control, the subject performs a dual task, solving the main task (insightful or non-insightful, visual or verbal) and simultaneously reacting to sound stimuli

Резюме

Отказ от стратегии сознательного поиска решения может быть механизмом инсайта. Ряд исследований показал, что контроль важен как для инсайтных, так и для неинсайтных задач. Из этого следует, что у контроля есть разные функции. Инсайт осуществляется в несколько этапов, на которых роль контроля различна. Вначале задача решается как неинсайтная, и контроль нужен для исследования ситуации. Это продолжается до тех пор, пока не будет достигнут тупик в решении. Далее, на первый план выходят интуитивные процессы: роль контроля снижается. Для изучения динамики контроля испытуемый выполняет двойную задачу: решение основной задачи (инсайтной или неинсайтной, зрительной или вербальной) и одновременное реагирование на звуковые стимулы (два уровня сложности

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(two levels of complexity of reactions). To study the role of control, we propose to use modally non-specific stimuli (sound signals) presented in the single tone paradigm. Twenty-five people took part in the study. No significant differences in dynamics were obtained. The probe-task was performed much more slowly from the middle stage of solving a non-insightful task to the end of the solution. The execution of the probe-task when solving the insightful task was uniform. A non-insightful task forces you to operate with voluminous intermediate data; this requires more resources of the central executor block.

Keywords: problem solving, insight, probe-task, working memory, dynamics of thought processes, executive functions.

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реакций). Для изучения роли контроля предлагается использовать модально неспецифические стимулы (звуковые сигналы), представленные в парадигме сингл-тон (англ. single tone). В исследовании приняли участие 25 человек. Значимых различий в динамике получено не было. Задание-зонд выполнялось значительно медленнее от среднего этапа решения неинсайтной задачи до конца решения. Выполнение задания-зонда во время решения инсайтной задачи было равномерным. Неинсайтная задача вынуждает оперировать объемными промежуточными данными, для чего требуется больше ресурсов блока центрального исполнителя.

Ключевые слова: решение задач, инсайт, задание-зонд, рабочая память, динамика мыслительного процесса, управляющие функции.

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Ponomarev (1976) suggested that insight is the rejection of a strategy of consciously controlled search for a solution and the transition to an intuitive and uncontrolled search for a solution to a creative task. In an algorithmic solution, the result image is present explicitly, the solution process can be described by the solver, and the approach to the answer is sequential. Consequently, control plays an essential role in solving the task: during the process of executing the algorithm, the solver monitors intermediate goals and compares one's actions to the image of the final result. Whereas in insightful solving the outcome is unpredictable (Ponomarev, 1976), the process is not consciously realized by the solver (Ohlsson, 1992), the answer appears suddenly and in the absence of an explicit conscious strategy (Metcalfe & Wiebe, 1987). At this point there is no unambiguous answer on whether insight solving and algorithmic solving are fundamentally independent processes, for example according to Ohlsson (1992), or whether these solutions are obtained through the same mechanisms and differ only phenomenologically (Weisberg, 1992). One of the main differences in the mechanisms of insightful and algorithmic decision-making may be the involvement of control processes. In our study, we define control as attention directed to the processes of operating at the task elements, maintaining representations in working memory (Awh et al., 2006).

We also have some contradictory findings here. While there is no question about the need of control for the algorithmic solution (Gilhooly & Fioratou, 2009; Murray & Byrne, 2005), in the case of the insightful solution we have a very rich diversity. There is evidence that control is necessary for insightful solutions (Robbins et al., 1996), has no role (Lavric et al., 2000), or inhibits them (Reverberi et al., 2005). We suggest that this contradiction may be explained by the fact that the authors do not take into account the dynamics of insightful decision-making. Insightful solution has several distinct phases which may be characterized by a fundamentally different role for control. At the beginning of the process there are attempts to solve the task as a non-insightful one and control is needed to perform calculations and monitor movements in the task space. All this continues until the solver reaches an impasse. At this stage intuitive processes prevail and the role of conscious control is minimized. It may even be harmful. Finally, after finding a principal solution, control again becomes necessary to check the suitability of the solution found and the final calculations (Ponomarev, 1976; Ohlsson, 1992).

Another issue is the low awareness of the processes involved in insightful solutions, so the application of indirect methods is useful in investigating them. Such methods can give us information about the processes of interest through their influence on other processes and phenomena. One such indirect method is the cognitive monitoring method we proposed earlier (Korovkin et al., 2014; Vladimirov et al., 2016; Chistopolskaya, 2017). The method involves parallel performance of a secondary task (a choice of two alternatives) with the main task. According to the dynamics of the secondary task performance disorders (decreased pace, mistakes), the method allows to reflect the dynamics of the managing control activity in the process of creative decision-making.

The most frequent probe-task is the material (Korovkin et al., 2014; Korovkin et al., 2018; Chistopolskaya, 2017) that involves loading subordinate working memory subsystems. However, in such a variant, we load both the subordinate subsystems and the central executive (Baddeley, 1992; Chistopolskaya, 2017), both through the tasks themselves and through the stimulus material (use of images or text). The complexity of such material itself and its impact on control functions is not always clear, and there is evidence of an ambiguous role of the phonological loop in this model. The phonological loop not only acts as a “container” for speech information, but also seems to be connected to the maintenance and management of action control. Even simple articulatory suppression such as the repetition of “the” impairs the task of counting and shifting attention (Baddeley et al., 2001). This makes it difficult to infer the role of control per se, and potentially disrupts the task solving itself. Simplification of tasks and monitoring stimulus material is important in order to draw more reasoned conclusions and to test the assumption of a task solving disorder with difficult types of tasks and/or monitoring stimulus material.

The monitoring method is fundamentally correlated with another promising method of investigating the dynamics of control functions during insightful decision-making (the method of recording evoked potentials). In particular, this method is close to the paradigm proposed by Lavric and colleagues (Lavric et al., 2000). The authors recorded evoked P300 potentials while solving insightful and non-insightful tasks. It was shown that during algorithmic tasks solving, the amplitude of the evoked brain potential component that reflects control function activity (P300) was higher than during an insightful task solution. This supported the assumption of a lower loading of the control functions. The data was also confirmed later in our study (Vladimirov & Smirnitskaya, 2018). In Lavric’s work, a passive single-tone paradigm was used. The subject was required to count the number of sound signals during the task. Varying the intermodal interval was used to reduce the attention habituation factor. Whether or not the subject performed the task was monitored through mistake analysis. The authors averaged EPs over the entire task time span; however, with this approach it is impossible to describe the dynamics of control during the solution process.

It seems to us promising to combine the Lavric paradigm with the cognitive monitoring paradigm. This would enable us to combine analysis of both behavioral and physiological data and obtain a full picture of the dynamics of control during the insightful decision-making process. However, it is difficult to combine current monitoring options with electroencephalography techniques for at least two reasons. Firstly, standard monitoring tasks are enough complicated to use them as EP triggers. Secondly, the existing tasks do not involve intervals in the stimulus presentation, whereas for evoked potentials these intervals are necessary, since in their absence the data from neighboring triggers would be mixed up with each other.

The aim of our study is to test a version of the cognitive monitoring technique that would, on the one hand, provide data on control loading in insightful decision-making that is comparable to classical variants. On the other hand, the stimulus used in it should be suitable as an EPs trigger.

Method

We suggest that control loading while solving an insightful task has specificity in comparison to a non-insightful task. This paper uses a dual-task method in a variant of cognitive monitoring involving competition for attention and working memory resources (Korovkin et al., 2014). The task creating the competition (a probe-task) is sound signals which subjects need to respond to according to the instructions.

Stimuli

To investigate the role of control, we propose to use modally non-specific stimuli, i.e. sound signals presented in the single-tone paradigm. The characteristics of the sound stimulus produced are: frequency 550 Hz, duration 200 ms with an interval of 3 seconds after the subject's response to the stimulus, and presented from closed earphones.

This paradigm in the study of evoked brain potentials can also be used in a passive version if the inter-stimulus interval is varied, as in Lavric's work (Lavric et al., 2000). However, when using this paradigm in conjunction with the main task, it is difficult to control the degree of attention to the auditory stimulus and so a control measure, the subject's response to the stimulus, is introduced. In order to control of the habituation and workability factor, we introduce more complicated instructions for responses than simply pressing a key.

In this experiment we vary two degrees of complexity: simple (alternating left-right key presses), complicated (alternating left and right keys, with double consecutive right key presses). Varying the complexity of the instruction allows us to change the load on the central executor block (managing control), which will enable the assessment of the contribution of these particular processes to problem solving.

In our research we use two insightful and two non-insightful tasks, two of them are verbal and two are visual, tested in the work of Chistopolskaya (Chistopolskaya, 2017).

An example of a verbal non-insightful task:

Marina is the sister of the daughter of the husband of Tatiana's daughter's aunt. What is Marina's relationship to Tatiana?

An example of a verbal insightful task:

Kirill spent three days in hospital. He was not ill or injured, but he had to be carried when he was discharged. Why?

The program PsychoPy 2021.1.4 was used to perform the experiment.

Procedure

The subject is given a training series with simple and complex instructions before solving the main task series. Before solving each task of the series, the subject can return to the training. During training before the main series reaction time is recorded. The training takes one minute for each type of instruction. The subject was then provided with an instruction for the series of tasks, before solving each task the instruction was repeated and the difficulty of the probe-task was clarified. After solving each task, the subjective insightfulness was monitored by using the Ellis scales (Ellis, 2012).

Instructions to the Subjects

A simple one: "You are asked to solve a task, and at the same time react as quickly as possible to a sound. Starting with the "LEFT" key, change to the opposite key for each subsequent sound. Example sequence: "LEFT", "RIGHT", "LEFT", "RIGHT". Press "SPACE" at the end of the solving."

A complicated one: "You are asked to solve a task, and at the same time react as quickly as possible to a sound by pressing the button left or right. You will have to press the keys in a certain order. Starting with "LEFT" followed by two consecutive presses of "RIGHT". Example: "LEFT", "RIGHT", "RIGHT", "LEFT", "RIGHT", "RIGHT". Each press for one sound. Press "SPACE" at the end of the solving."

There is no time limit for solving the task. The task is solved until the subject has answered it correctly. While solving the task, the subject simultaneously performs a secondary task (a probe-task).

The sample consisted of 25 subjects between the ages of 18 and 45 ($M = 20$, $\sigma = 8.5$). Thirteen males and 12 females took part in the study.

Analysis and Discussion of Results

The results show that the tasks behave as in the paradigmatic work, are solved in comparable time and are not complicated by the probe-task. The data from the questionnaire (a structured post-experimental interview) developed by Ellis (2012) was used as one of the variables to control for insightfulness of decision. Based on the results, we can conclude that the tasks we classified as insightful are indeed solved insightfully compared to the algorithmic tasks. We observe significant differences in the criteria 'solution suddenness', $t(90) = 2.61$, $p = .01$ and 'knew solution direction', $t(90) = -2.4$, $p = .01$, i.e., tasks that were assumed to provoke an insightful solution were indeed rated as insightful (the solution came up spontaneously and the solver did not know which direction to take). Consequently, this type of probe does not affect the type of task solution.

No significant differences in solution time depending on probe-task complexity were found nor was a cross-effect of monitor complexity and task type. Only differences between insightful and non-insightful tasks with a complicated probe are observed. It is higher for insightful ones, $F(1, 23) = 8.07$, $p = .009$, $\eta_p^2 = 0.26$. (see Figure 1).

In analyzing the pace of the probe performance (average response time per time interval), we found significant differences. The influence of the factors 'instruction complexity', $F(1, 528) = 18.56$, $p < .001$, $\eta_p^2 = 0.03$ (the more complicated the probe-task, the lower the pace) and 'task type', $F(1, 528) = 8.77$, $p = .003$, $\eta_p^2 = 0.02$) (the pace is lower for non-insightful tasks) was observed, while there was no combined effect of these factors (see Figure 2). This is consistent with the typical structure

Figure 1

Insightful and Non-Insightful Tasks

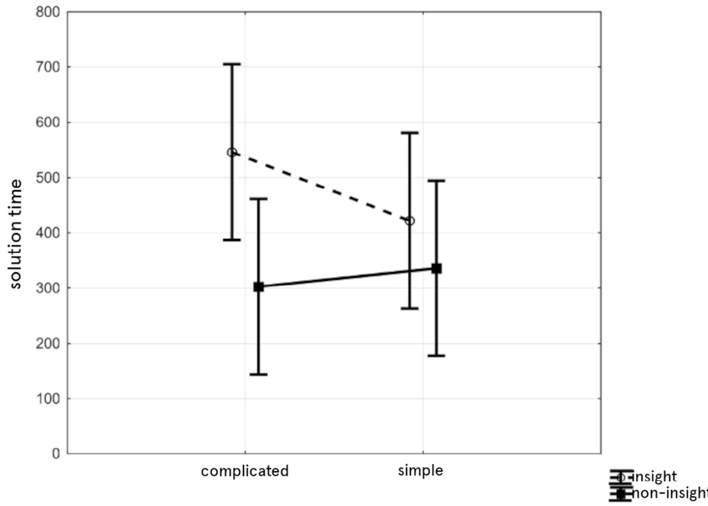
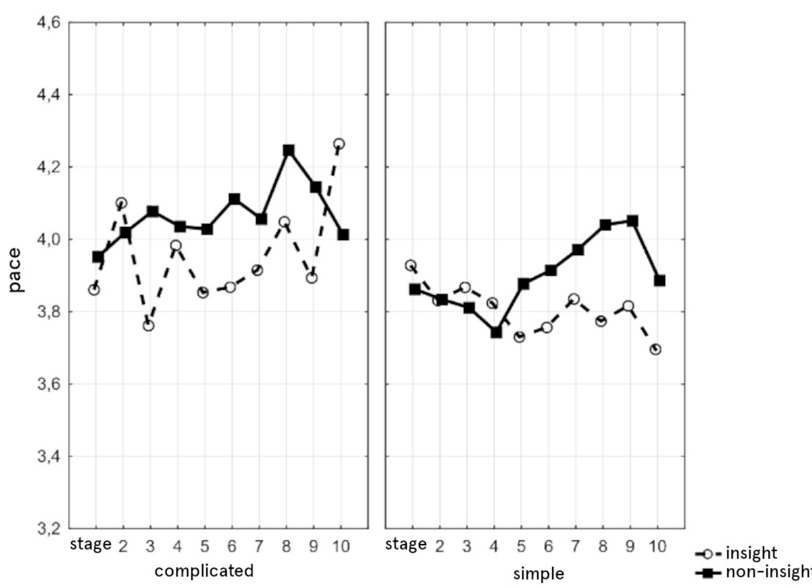


Figure 2

Diagram of response time dynamics to the secondary probe-task for the insightful and non-insightful task for both complicated and simple probe-tasks



of the data obtained in the monitoring paradigm: when solving in conjunction with non-insightful tasks, probe response times are higher than in insight conditions, which indicates a greater importance of control for non-insightful solving (Lavric et al., 2000; Korovkin et al., 2014). In our case, it also suggests that our tasks in the behavioral experiment produce a picture of results identical to those obtained using probes that are classical to the monitoring paradigm.

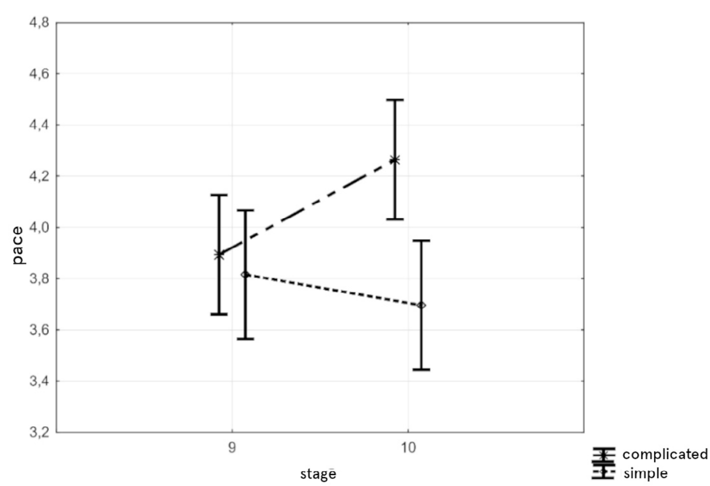
Observing the absence of differences in the solution time and the presence of such differences in the pace of the secondary task, we can say that this type of probe in both the simple and the complicated versions has no significant distorting effect (distraction) on the process of task solving, but at the same time allows monitoring changes in the working memory load. Combined with the suitability of the stimulus we used for recording evoked potentials, this will provide for their use in studies of insightful solution dynamics through the combined application of the monitoring paradigm and electrophysiological methods.

While there are no dynamics in the pace of the task performing, reflecting the working memory load, namely the central executor block, throughout the entire stage of the task performing, we can detect dynamics in some periods of the solving. Thus, for solutions with a complicated probe-task, we observe an increase in loading at the last stage of the solving, $F(1, 26) = 4.65$, $p = .04$, $\eta_p^2 = 0.15$. At the same time there is no such dynamics with the simple probe (see Figure 3).

Such data, firstly, correlates with the already known results of the effect of probe complexity on the dynamics of its execution: a complicated probe demonstrates increased loading of the central executor block when solving insightful tasks (Korovkin et al., 2018). This further confirms the validity of our proposed probes in the context of the monitoring paradigm. Second, the presence of two stimuli, one of which shows the dynamics of the central executor block at the level of the behavioral experiment, allows us to vary the application of the technique with maximum flexibility when combining it with the evoked potentials paradigm.

Figure 3

Diagram of the dynamics of the response pace to the secondary probe-task for the insightful task for complicated and simple probe-tasks at the final stages



Conclusion

To summarize, we can draw the following conclusions:

1. The probe-tasks we used provide a cognitive monitoring picture comparable to classical stimuli. Accordingly, we can use them at the behavioral level to measure the loading of control functions (of the central executive) in the insightful decision-making process of a behavioral experiment.

2. Since the stimuli were initially selected so that they could be used as triggers for recording evoked potentials, we can use them when combining behavioral and electrophysiological methods, which will then provide a more complete picture of the dynamics of control function involvement in the insightful solution.

3. The influence of probe complexity on the manifestation of the control function dynamics that we have identified can be used to fine-tune methods in combined psychophysiological studies with the combined usage of cognitive monitoring and evoked potentials paradigms.

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