The Role of the Central Executive and Slave Systems of Working Memory in the Insight Problem Solving

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Abstract

This paper deals with an investigation of specific mechanisms of insight problem solving. We take the functioning of working memory slave system as such mechanisms. In our research we use a dual task method as a cognitive monitor (D. Kahneman) to fixing of microdynamics for study mechanisms of thinking processes. We gathered data showing that modal-specific blocks of working memory are mainly used during insight problem-solving, while solving algorithmic problems uses mainly executive control.

Keywords: problem solving; working memory; insight; dual task; microdynamics.

Introduction

To date, the psychology of problem solving did not settle the question about the legality of allocation of insight problems in a special category. Accordingly, there are two alternative positions. Participants of the first approach (Duncker, 1945; Metcalfe, Wiebe, 1987; Seifert., 1995, Ohlsson, 1992, Knoblich,, 1999 et al) insist on specificity of the process of insight solution. Another point of view is held by representatives of non-specific approach, which denies the specificity of insight problems as related to algorithmic problems. They believe that any problem can be reduced to an algorithm (Newell, Simon, 1972; Weisberg, Alba, 1981, MacGregor, Ormerod, Chronicle, 2002 et al). In cognitive psychology, in general, and in the theory of insight problem solving in particular, there are virtually no data to get a clear idea of the microdynamics of the thought process, including solutions of insight problems. Typically, studies on this subject are exploratory, phenomenological, that do not set a goal to reveal the underlying mechanisms. The existing experimental studies mostly don’t reveal the current solution's genesis of both algorithmic and insight problems. Basically, in the study of the specifics in this case methods of distraction, pre-intervention (creation of emotional background, creating the effect of setting, etc.) are used. (Wen, Butler, Koutstaal, 2013; Lyusin, 2014). An alternative is the research carried out in the paradigm of differential psychology (Hambrick, Engle, 2003). Available methodical arsenal can reveal informative, structural specificity of insight processes, but has significant limitations at revealing the dynamics of insight process. Classical methods of psychology of thinking, such as the the analysis of thinking aloud protocols (developed by K. Duncker) and analysis of sections of representations do not answer this question (about the microdynamics of thought process) because:

- They have an impact on the process of decision by interfering with him, distorting his move.
- As a rule, they are based on the verbal report, and include analysis only conscious components of thought process. Thus, there is a significant reduction basically to the phenomenological piece of the process under consideration.
- They have a very low "sampling rate", while the process of solutions (especially insight solutions) is often minimized and meaningful phases of solutions can take micro intervals (thus only rough analysis of the dynamics is possible, which is insufficient for reveal the mechanisms of insight solutions)

One more method is the analysis of movements on decision tree, used in the works of A. Newell and H. Simon (Newell, Simon, 1972). The analysis of movements on the decision tree, in turn, is imposed interpretive by the scheme priori: it is assumed that the solution to every problem is a consistent movement between adjacent representations. Among the methods that allow to reveal the microdynamics of the solving process the monitoring method should be allocated.

The monitoring method is based on the D. Kahneman's uniform resource model and implies the parallel solution of dual tasks. The monitoring method is based on the D.

Kahneman's common resource model and involves simultaneous solution of two tasks. According to the Kahneman's model, different structures require different amount of attention. In addition, their resource requirements vary in different time moments. The total amount of mental effort (resource) that is potentially available for a system of information processing is limited. In order to test the degree of attention he used the method of the secondary probe task. The main idea was that it can be possible to "catch" the moment of the resource's depletion when the subject deals with the main problem (complex) and, paradoxically, cannot cope with the additional secondary problem (simple). The difference between total effort and an effort that is invested in the core activity, D. Kahneman calls the spare capacity. Spare capacity is reduced with the increasing of an effort required to perform primary problem. Additional (secondary) problem can only be solved using spare capacity. If the primary problem requires more cognitive effort, the spare capacity is reduced and the productivity of the secondary task solution is reduced by the same amount, and vice versa. Consequently, the change of productivity of the secondary task reflects the change in the degree of mental effort that is invested into primary problem. Considering attention as a limited resource of mental effort was further developed in theoretical and applied investigations. Thus, D. Navon and D.Gopher (Navon, Gopher, 1979) proposed a model of integrated resource information processing, i.e, plurality and specificity of human's energy resources. The degree of interference between the tasks depends on how similar the combination of resources is required to complete each of them. Thus, the theory of resource's limitations formed the basis of the dual task paradigm, and this type of the method may be used for dynamics description.

Method and experimental design

The dynamics of the resource loading on the main task is determined by the productivity of the performance of the secondary task. The primary is a thinking task (problem) and a tempo task (choice of two alternatives) performed in parallel. The reaction time and a number of errors in the implementation of the second task are fixed. The dynamics of the performance quality serves as a marker of the loading of working memory by operations which are carried out in the main problem. The secondary task must satisfy a number of requirements:

a) the equal complexity,
b) the same procedure of the presentation,
c) the dichotomous choice,
d) the equal probability of alternatives (50/50).

Decreasing productivity at a given time moment indicates that currently the resource is used by the primary task. The main problem's leading representation format (insight / algorithmic) was varied: visual or text. Similarly the type of the probe task was varied. It was required to determine the type of the angle (obtuse - acute) - visual format, or to determine the type of the syllable (open - closed) - text format. It is assumed that the coincidence of the format of the probe task and the main task creates the competition for a resource and affects the dynamics of the probe-task. To describe the dynamics and results unification the time to solve each of the problems was divided into ten equal time periods. This made it possible to unify the different time solving problems of different problems in our experimental trial.

The problem was the fact that the subject has to correct the incorrect mathematical statement by moving one match and parallel to determine the type of syllable. After the participant has identified the first syllable by pressing the corresponding key, the following syllable was presented. So until then, until the problem is resolved. In this case, we see different formats of leading representation of tasks. There are visual algorithmic problem and the textual probe task.

Figure 1. The original example of an experimental task

(the different formats of leading representation of tasks)

And at this figure, we can see the same format leading representation of tasks. There are visual algorithmic problem and the visual probe task. It’s assumed that in this case cognitive load is higher and the execution of activity is more difficult.

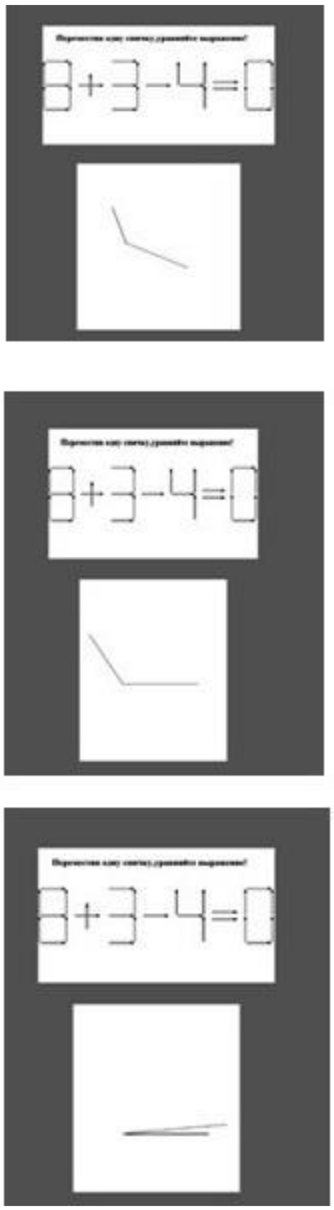

Figure 2. The original example of an experimental task (The same formats of leading representation of tasks)

The Stimulus material was prepared using PsychoPy - an open-source application to allow the presentation of stimuli and collection of data for a wide range of neuroscience, psychology and psychophysics experiments. It’s a free, powerful alternative to Presentation or e-Prime, written in Python (Peirce,2007)

Hypotheses:

The hypotheses are:

- There is a specificity of insight solution process regarding algorithmic solution;
- There is a domain specificity of information processing in the process of insight problem solving: the nature of the insight solution's dynamics can be reflected in the dynamics of the operation of slave systems of working memory.

The independent variables are:

1) the type of problem (insight / algorithmic)

2) the leading representation's format of the main thinking problem (visual / text)

3) the representation's format of probe task (visual / text)

The dependent variable is the productivity of the probe task (reaction time)

So, the subject of this study is specific information processing in insight problem solving

Participants. 58 people participated in total.

(Average age is 24 years, from 18 to 56, 36 male and 22 femail. SD = 6). They were asked to solve 8 problems, but first they performed two training tasks.

Results

1. The Role of the Central Executive in Solving Problems of Various Types.

Investigation of the role of the central executive in solving insight and algorithmic problems was carried out by comparing the data in the performance of all tasks without focus on its representation format. An important fact is the reproducibility of the results. The graph below shows the results of two experiments performed in a uniform methodological paradigm.

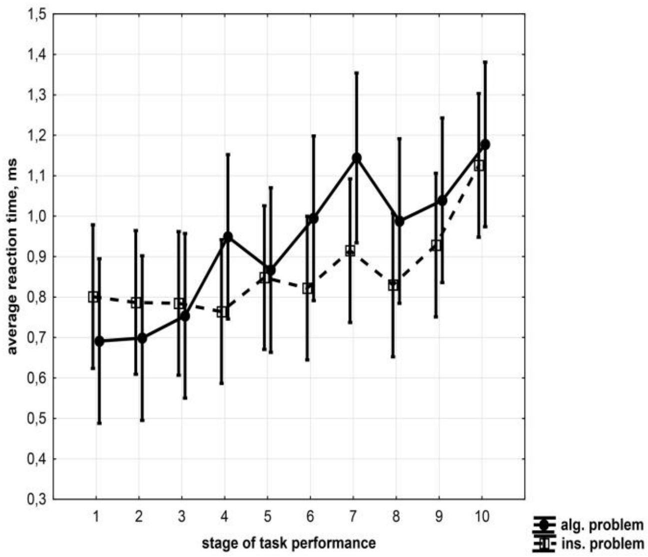

Figure 3. The dynamics of reaction time on performing the probe-task in parallel solution of the main thinking problem (insight / algorithmic) in provisional experimental series (cited by Korovkin, Vladimirov, Savinova, 2012)

Vertical bars denote 0.95 confidence intervals.

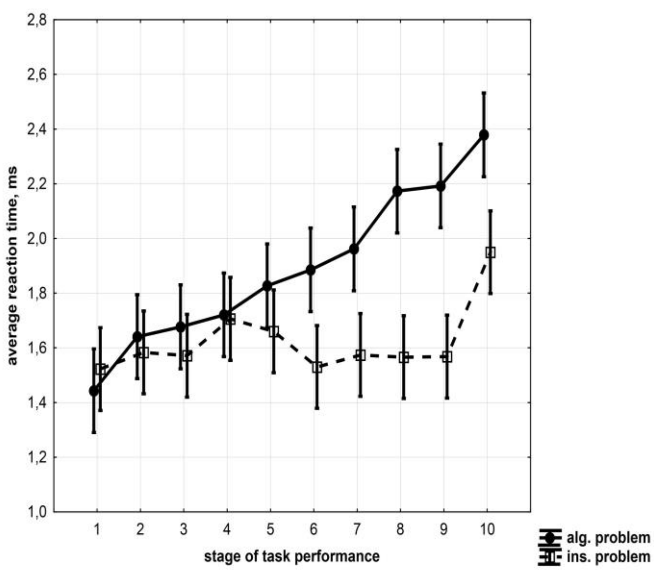

Figure 4. The dynamics of reaction time on performing the probe-task in parallel solution of the main thinking problem (insight / algorithmic) in main experiment trial. Vertical bars denote 0.95 confidence intervals.

There is the graph of reproducibility in two experiments. The results of the first experiment are shown in Figure 2. There is a significant dynamics in insight solving problems and its absence in algorithmic problem solving (Alg: $F(9, 149)=2.3$, $p=.02$; $\eta=.12$. Ins: $F(9, 200)=1.7$, $p=.09$; $\eta=.07$)

Similar results were obtained in our experiment (Figure 2). But in our trial all results are significant (Alg: $F(9, 1479)=3.62$, $p<.001$; $\eta=.06$. Ins: $F(9, 1479)=10.12$, $p<.001$; $\eta=.02$) (Figure 3).

We can observe that the data structure is reproduced. The greater complexity of the task in our series (more reaction time) is explained by more complexity of the probe-task (assignment to one of the two categories of 24 stimuli, whereas in the cited work the incentives were only two). We found the presence of the dynamics of working memory's loading in solving algorithmic problems. The expressed dynamics is manifested in the presence of a "hump" near the end of the solution. High productivity decreases on the steps of low-cost operations: the reading of the conditions and the voicing of the answer. Probably, the decrease in productivity near the end of the solution is connected with the implementation of combinatorial operations.

2. The Role of Domain Specificity Units of Working Memory in Solving Problems of Various Types.

Also, one of the results of the above-cited studies (Korovkin, Vladimirov, Savinova, 2012) was the lack of a dynamics on the insight problem solving. As a possible reason was the suggestion that manipulations with a representation are important in insight problem solving and domain specific units of working memory are utilized rather than central executive. The purpose of this series was to investigate the loading of slave modal specific systems of working memory as a possible locus of information processing in the insight solutions. Separately for insight and algorithmic problems let us consider the data on the average rate performance (average reaction time) of the probe-task in conditions when its format of representation matches the format of the thinking problem and in conditions of the discrepancy between these formats.

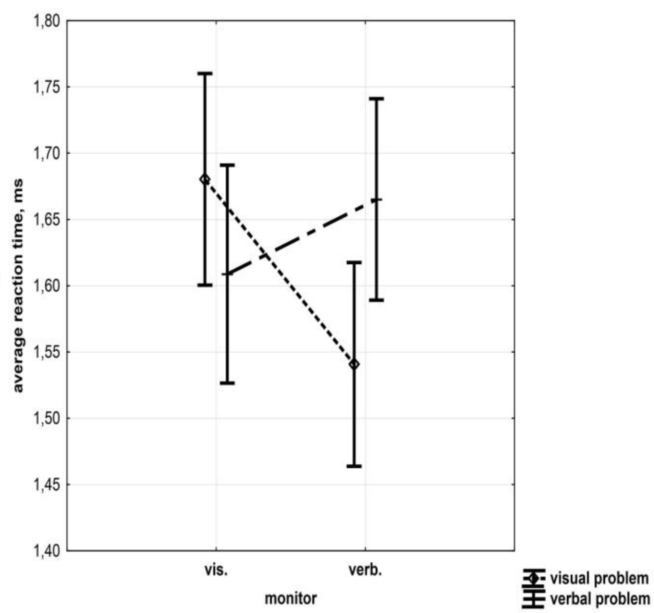

Figure 5.The effect of competition of resource on the average reaction time in performing the secondary probe-task in parallel solving insight problems. Vertical bars denote 0.95 confidence intervals.

There is a expressed cross effect (F (1, 1527) =5.96, p=.01; η=.003). When there is coincidence of the leading type of the representation of the main tasks and the probe-task in the solution of insight problems then we observe a significantly lower pace of implementation of the secondary task (probe-task). Especially pronounced effect is for visual representation. A different picture is observed in algorithmic problems.

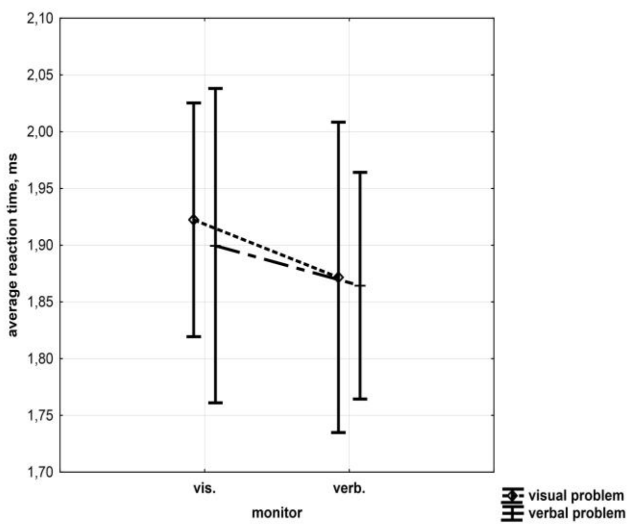

Figure 6.The effect of competition of resource on the average reaction time in performing the secondary probe-task in parallel solving algorithmic problems. Vertical bars denote 0.95 confidence intervals.

As can be seen from the graph in the algorithmic type of tasks the cross effect (F (1, 1493) =.01, p=.9; η<.001) is not expressed. Probably, these findings can be explained by the fact that in solving insight problems more important is to manipulate with the initial representation of the problem, especially for the "visual" problems where the spatial characteristics and moving into the field of the problem are important because of high uncertainty of problem space. In the type of algorithmic problems, apparently, the central executive is more important because the main resource burden falls on a phased program switch solutions that do not require taking into account the modal specifics, but it's rather more complicated switching between tasks of different modalities.

Summarizing, the data show that slave systems of working memory are less important for algorithmic problems. Central executive plays the main role and allows to keep the algorithm of solutions.

Accordingly, the model designed by H.Simon and A.Newell (1972) - the model of problem space, which describes the solution process as a successive movement on the graph of possible intermediate states between the condition and purpose most adequately describes the process of algorithmic problems. Slave systems are loaded harder in the process of solving the insight problem. In this case, a subsystem of the same representation's format of the basic problem is maximally loaded. Most clearly this fact is expressed for the spatial type of representation. The data allow us to assume that when a subject solves insight problems, he manipulates with his own representation by searching elements and their correlations. Probably, this process corresponds to the model of problem's field proposed by Karl Duncker and has quasi-spatial structure.

Conclusions:

1. A consecutive movement on the decision tree underlies the solution in the course of solving algorithmic problems. A significant role in this process is played by the central executive. For insight problems such process is not characteristic.

2. A non-directional movement in a field of the problem (obviously, it's a spatial or quasi-spatial structure) underlies the solution in the process of insight solving problems.

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