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FROM "HMMM..." TO "AHA!": EMOTIONAL MONITORING OF REPRESENTATIONAL CHANGE

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Abstract

There are two common approaches to researching insight: the study of the emotional response to a solution (Aha! experience) and the study of the restructuring of representations. The relationship between them can be found by comparing functions they perform relative to each other. For the experimental investigation of insight, problems that are typically being used can be solved within a little amount of time and are highly similar in their structure. We believe that such laboratory designs of the tasks often lead to researchers missing out on the moments of impasse and initial restructuring of the search space. In the current study, using the method of multimodal corpora constructed from individual solutions, we gained partial confirmation of the key statements of the model of emotional regulation of the representational change. According to the model, an insight solution process is accompanied by emotions regulating the process of representational change. A feeling of impasse is a response to the lack of progress towards the solution. An Aha! experience appears in response to solvers performing actions that bring them a huge step closer to the solution of a problem. We believe that these emotional responses are experienced before the solution reaches consciousness and they motivate the solver to adapt their search space accordingly. The model we propose is a development of the ideas of Ya.A. Ponomarev on the role of emotions in regulating of insight problem solving andmodel of M. Ollinger and colleagues describing the phases of insight problem solving.

Keywords: insight, problem solving, impasse, emotions, linguistic multimodal corpus.

Introduction

Since psychologists started to investigate insight they have tried a multitude of various approaches to the phenomenon (Dunker, 1945; Köhler, 1972; Wallas, 1926). Currently the two most popular ways are: investigation of cognitive mechanisms (first of all, representational change theory; Knoblich, Ohlsson, & Raney, 2001; Ohlsson, 1992, 2011; Öllinger, Jones, Faber, & Knoblich, 2013) and affective processes (especially studies on the Aha! experience; Bowden & Jung-Beeman, 2003; Danek, 2018; Danek, Wiley, & Öllinger, 2016; but also research into the feeling of closeness to a solution also known as the feeling of warmth; Metcalfe & Wiebe, 1987). At first glance, these paradigms consider different

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aspects of insight problem solving and there is little in common between them. However, a comparison of the various paradigms and models gives a chance to make significant progress in understanding the nature of insight.

One of the ways to compare cognitive and affective insight models is the dynamics of insight problem solving. Both models make an attempt to explain events in different solution stages. In the introduction we will discuss problem solving models focusing on cognitions and emotions in insight problem solving; we shall try to understand how a joint consideration of these processes may enrich theoretical models of insight. G. Wallas's classic 1926 work can be considered the source for both ways. Wallas's work discusses changes in problem understanding and emotions with regard to their relationships.

Ya. A. Ponomarev was one of the first researchers who declared an interconnection between emotions and cognitions, and revealed mechanics of their interactions (Ponomarev, 1976). According to his understanding, emotions regulate cognitive processes. In particular, an experience of impossibility to solve the problem by a known way can cause the solver to switch from a rational search mode to an intuitive mode, while the intuitive discovery of a solution is accompanied by positive emotions (the Aha! experience). These emotions lead to solution awareness.

Cognitive Processes in Insight Problem Solving

The pioneer models of cognitive processes in insight problem solving are linear. They describe problem solving as a one-way path from a beginning to a solution. G. Wallas (1926) distinguishes four stages (preparation, incubation, illumination and verification), which the solver sequentially passes from the beginning to the end. A similar view is observed in the K. Duncker model (1945): the solver first finds a functional solution and then implements the solution. Such linearity can be explained by focusing attention on successful solution cases or by the simplicity of problems. The modern linear models are mainly used to describe simple problems: RAT (Jung-Beeman et al., 2004), anagrams (Ellis, Glaholt, & Reingold, 2011), and arithmetic matchstick problems (Knoblich et al., 2001). The Duncker model (1945) and especially the problem space theory by A. Newell and H. Simon (1972) already contain the possibility of rejecting the wrong solution or the search path, but this idea remains undeveloped in these models. The models resulted from the analysis of successful solutions. However, the analysis of difficulties and causes of failures in insight problem solving enables an understanding that, along with finding a solution, there is an important stage, the impasse. The impasse must be overcome to reach the solution (Ohlsson, 1992). However, some researchers suggest that insight without impasse is possible (Kounios & Beeman, 2014). They consider many possible definitions of insight, such as "... the broadest definition of insight is the common nonscientific one in which an insight is any deep realization, whether sudden or not". But a broad definition includes not only an insightful solution, but also phenomena such as pattern recognition and reading complex texts. We believe that it is possible to use various combinations of insight attributes to define it. But the combination of impasse plus restructuring is the best, as it cuts out similar phenomena.

After that various models appeared (Beeftink, van Eerde, & Rutte, 2008; Öllinger, Jones, Knoblich, 2014). M. Öllinger and colleagues (Öllinger et al., 2014) describe three possible solution paths that differ in the contained stages: a solution without insight, an unsuccessful solution, and an insight solution by overcoming the impasse. Further development of Representational Change Theory leads to a rejection of the concept of solving process as movement through sequential stages. The theory starts to describe the solution as a cyclic process (Ohlsson, 2011; Fedor, Szathmáry, & Öllinger, 2015). A. Fedor and colleagues (Fedor et al., 2015) show that overcoming the impasse and building a new representation that differs from the initial representation, does not necessarily lead to a solution. The new representation can also lead to a new impasse and require its overcoming. The authors dispute the concept of stage and propose to consider the solution process as cycles of changing modes (Ibid.). The cycles involve manipulations with elements of the current problem representation and the construction of a new representation through a destruction of the old representation. The cyclic solution model is the most accurate way to describe the solving process phenomenology (in particular, cases of failure and multiple errors in the problem solving). However, the model does not explain: how and why solution stages are changed; why people move in the problem space not randomly, but in accordance with requirements. S. Ohlsson partially answers the first question describing the representational change mechanism that is linked to overcoming the impasse. The mechanism of representational relaxation is a negative feedback received from actions within representation that do not move the solver to a solution (Ohlsson, 2011). However, the nature of the negative feedback is not clear. We suppose that the role of the negative feedback may perform emotions arising from problem solving events.

Emotional Processes in Insight Problem Solving

One of the most famous works on the relationship between emotions and metacognitive feelings in insight problem solving shows the suddenness of solution (Metcalfe & Wiebe, 1987). This result demonstrates the paradox: the solution process is purposeful, but it is unconscious. In our opinion, there are two main causes. Firstly, authors use a linear model of solving processes that does not reflect nuances of representational change. Secondly, the dependent variable in the experiment is an assessment of solution proximity. The task is difficult for the solver during the solution. It becomes easier only on the answer stage or immediately before the answer. Recent studies link emotion roles and emotional reactions to solution stages or directly to the answer. The results are encouraging. For example, the Aha! experience for correct and incorrect solutions is different (Danek & Wiley, 2017); solvers can adequately evaluate that they are in an impasse (Fedor et al., 2015; Markina, Makarov, & Vladimirov, 2018); the components of the Aha! experience are associated with the representational change (Danek & Salvi, 2018). To understand the relationship between emotions and representational change it is necessary to know about the functions of emotions in problem solving.

Analyzing studies about the relationship between emotions and the dynamics of insight problem solving allows us to propose three hypothetical functions of emotions:

1. Emotion as a feedback (Danek & Salvi, 2018; Tikhomirov, 1983; Valueva, Lapteva & Ushakov, 2016).

2. Emotion as a reward. It motivates the solver to seek the answer (Danek, Fraps, von Müller, Grothe, & Öllinger, 2013).

3. Emotion as a marker of a solution. It makes easier further recall (Ibid.).

The first function is the main focus of current research. A number of studies have shown that a positive Aha! experience may precede the awareness of a solution (e.g., Valueva, Lapteva, Ushakov, 2016; Tikhomirov, 1983). But negative emotions (e.g. the sense of the impossibility finding an answer) may accompany the impasse stage (Fedor et al., 2015; Markina et al., 2018). We will try to combine these facts with the cyclic solution model (Fedor et al., 2015), and will formulate general statements of the model that describe emotions as feedback to switch between solution modes. According to the model, negative emotions should signal about the impossibility to achieve the goal in the current representation. At the same time, negative emotions trigger processes of the representational destruction. Positive emotions should indicate a promising solution path and trigger processes of a new representation construction.

The *main assumptions* of the model are:

1) Insight problem solving is accompanied by two groups of emotional responses (negative and positive). Emotional responses signal the solver about the solution process state and allow changes in the direction of searching for a solution. Negative emotions (the feeling of impasse) are reactions to the lack of progress during problem solving based on the initial representation (initial search space). Positive emotions (the Aha! experience) are reactions to randomly performed actions that move the solver significantly closer to the answer.

2) These emotional responses precede the awareness of the solution. They motivate people to move within the problem space on the detected path. We suppose that the sequence of representational change under control of emotions looks as:

a. The solver is confident that she or he can find a solution. The solver has the initial representation. It guides her or his search activity in the problem space. The person carries out a number of actions for clarifying the problem space. The result of actions will be either moving to the goal or the illusion of moving to it.

b. Solvers' actions, guided by the initial representation, cease to bring them closer to the goal and begin to slow down and/or repeat. Participants experience it as a feeling of impasse. The feeling of impasse allows inhibiting the current representation of the problem, and thus, search space.

c. The solver performs chaotic activity (makes random moves without a goal) in the problem space. The sequence of actions is experienced as correct if it brings the solver closer to the goal. Later this feeling evolves into the Aha! experience. The Aha! experience leads to the new representation and search continues within this changed search space.

d. If the new representation is not adequate to the problem requirements, the sequence will be repeated.

These assumptions are tested in the current study using the method of corpora linguistics.

The Current Study

To test our assumptions, certain requirements should be met. Firstly, there are requirements for problems. These problems should be sufficiently difficult and have clearly distinguishable types of representation. Moreover, the types of representation should also be distinguishable by the participant's behavior and speech production. For our experiments we chose two rarely used insight problems: Zakharov's problem (Zakharov, 1963) and

"How many cars are in the garage?" (Makarov & Vladimirov, 2019). The problems are described in the Material section of Experiment 1 and Experiment 2. Two problems were used to assess the reliability of results.

Secondly, there are requirements for the experimental design. The paper of A. Fedor and colleagues (2015) showed that an experimental design is good for well-defined linear models, but it leads to the loss of individual solution nuances. Attempts to take into account the individual trajectory of problem solving were made to check the cyclic solution model. For this purpose, a rigorous experimental plan with a variation of conditions was not used. The conditions were the same for all participants, i.e. every part of the current research did not contain independent variables; instead, the recordings of the solutions were analyzed. The analysis yields data about events and their temporal characteristics (start time, duration). According to the model, assumptions must happen in a very specific order. In order to test that, logistic regression was applied.

Thirdly, there are requirements for the highlighting events and the techniques of formalizing them. Traditionally, the representational change is recorded either by information search activity (Ellis et al., 2011; Jones, 2003) or by self-reports (Fedor et al., 2015). Changes in emotions are estimated more often by a self-report questionnaire (Danek & Wiley, 2017) and sometimes by behavioral or physiological parameters (Tikhomirov, 1983). In our paper information about cognitions and emotions was collected from comparable sources (the behavior and verbal production). The data is the result of a markup of video recordings of problems solving processes.

We used the ELAN program to markup our data. ELAN stands for EUDICO (European Distributed Corpora Project) Linguistic Annotator. ELAN was created by the Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands (Lausberg & Sloetjes, 2009). ELAN data is divided by custom defined layers. One layer includes one type of events (e.g. the "Speech" layer contains every word spoken; "Facial expression" can contain "happiness", "anger", "fear", etc.). Every event has a time interval with the beginning, end and duration. The information about time can be used to compare any number of events. ELAN can compare relationships between events such as inclusion (when one event happens during another), exclusion (when an event happens without another), intersection (when events coincide at a predetermined time interval) and etc. These comparisons can be made for any events.

The idea of the method of corpus linguistics for markup is a development of exploratory analysis. There are pros and cons of the corpus method in comparison with the confirmatory approach. That is, we can collect a significant amount of data that helps to understand phenomenology, but there is no manipulation of independent variables. And without independent variables it is hard to reason about cause and effect. A corpus (corpus markup) stores a participant's behavior as is, keeps all recorded features of the investigated process and all the data is available for further research. The corpus can be used to verify new hypotheses, to mark up new events and to use them to analyze. The usage of corpus markup in psychology is a beneficial addition to experimental methods. Corpus research can collect detailed descriptions of phenomena and use it to build a theoretical model. The model could be verified in experiments.

Thus, we used the corpus linguistics method and created a labeled corpus of solutions to each problem. The results may be used to test our model and to test hypotheses of other researchers.

Based on the method, we make the following predictions:

1. Negative emotions arise after behavioral patterns of impasse and the participant still has the initial representation.

The solution process of the problems is divided by sets. The set is a unit of measurement and is defined as a group of attempts to solve a problem: 5 answers to the problem's question in "How many cars are in the garage?" and 3 moves in Zakharov's problem (Zakharov, 1963). A set can be viewed as an interval from the problem onset to the first interruption, or between interruptions. The set contains all events that happened during the set. Sets are required to use logistic regression. Comparison of a single attempt time and the mean attempt time plus two standard deviations (calculated separately for every participant) was used to detect an impasse. If the single attempt time was greater than the mean attempt time plus two SD, then the attempt is labeled as an impasse. If a set contains an impasse attempt, then the set is labeled as an impasse set. Negative emotions are recognized by the expert. There were two experts but their work was done on different parts of corpora. Experts had psychological education and at least 3 years of experience in psychological experiments. Negative emotions are registered in the next set of attempts after the impasse set.

2. Negative emotions predict the appearance of chaotic activity.

Negative emotions are defined the same way as in the previous prediction. Chaotic activity is detected by the participants' verbal production. We expect that the chaotic activity will follow after the set of attempts with negative emotions.

3. Positive emotions follow the representational change.

The representational change is detected by changes in the nature of actions and participants' explanations to their actions (for Zakharov's problem) and by behavioral and oculomotor patterns that indicate alterations in the attention focus on the problem (for "How many cars are in the garage?"). Positive emotions are defined the same way as negative emotions in the previous predictions. Positive emotions are expected to appear in the set following the set with the representational change.

4. Positive emotions predict the awareness of representational change.

The awareness of representational change is determined by a description of the solution principle or the answer in the participant's report. Emotions are defined the same as in the previous predictions. We assume that positive emotions will appear in the set preceding the problem solution.

Experiment 1

Experiment 1 was conducted to investigate the relationship between emotions and representations in insight problem solving. In the experiment we used an objective data recording of the representational change by an eye-tracker. As far as we know, no one has previously used the corpus linguistics method for the markup of insight problem solving. Thus, we would like to record a problem solving process and show how changes in the emotional state and the representational change happen during the solution.

We recorded a problem solving process for the problem "How many cars are in the garage?" (Makarov & Vladimirov, 2019). In the problem, the instruction attracts attention to the irrelevant zone for the problem solving, whereas the relevant zone is located in another place in the space. The transition of attention to the relevant zone may be detected by an eye-tracker. We assume that the problem provokes the insight solution, because the solution is assumed to be impossible with the initial representation, and the representation leads to an impasse. According to S. Ohlsson (1992) the insight criteria are overcoming the impasse and representational change afterwards. In addition to that participants evaluated the problem as insightful. We therefore assume that the problem is an insight problem in the cognitive and affective sense. It is very important, because in our work we want to investigate the relationship between cognitions and emotions. We suppose that participants will have strong emotional reactions while solving a problem that can be easily detected. The video markup allows a comparison of the temporal relationship between emotional and cognitive events.

Method

Participants

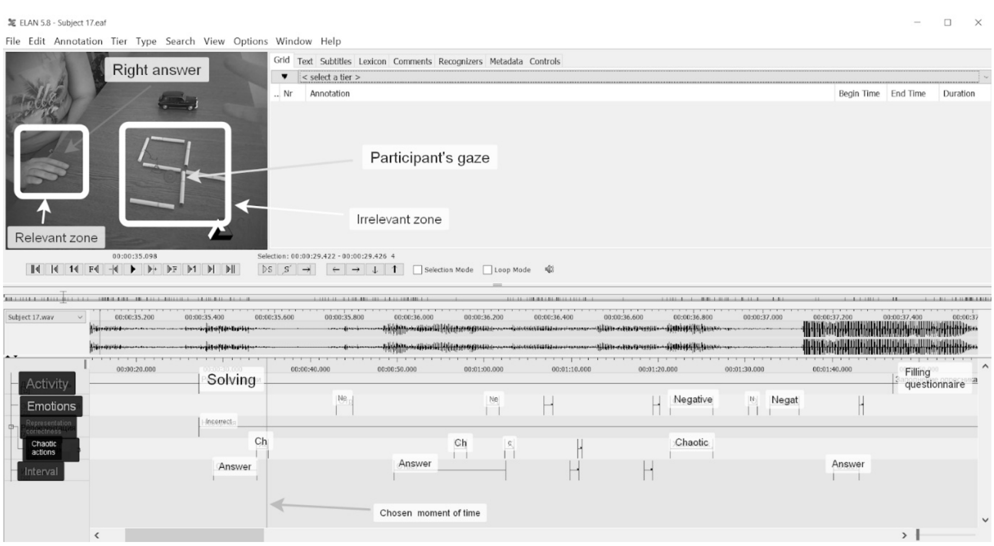
There were 13 participants (10 female and 3 male), aged 18–63 (M = 28.03, SD = 16.57). The majority of the sample consisted of undergraduate and graduate students at Yaroslavl State University. All participants were tested individually, took part voluntarily, and were not paid for their participation.

Stimuli

We used "How many cars are in the garage?" as the insight problem. In this problem, the participant answers "how many cars are in the garage" (0, 1, 2, 3, 4, or 5 cars). There are two zones that participants may focus on: relevant (fingers of the experimenter) and irrelevant (a figure made of sticks on the table) (see Figure 1). The instruction is mislead-

Figure 1

Still Video Frame of the Problem "How Many Cars Are in the Garage?" and an Example of the ELAN Markup



ing and switches attention to the irrelevant zone not associated with the correct answer. The instruction was misleading because the problem, according to Ohlsson model, requires constraint relaxation. The constraint is the result of previous experience of the solver, i.e. as a rule relevant for the solution are elements that are described in the instruction (e.g. matchsticks, figures, etc.) and irrelevant for the solution are other objects in the field of view (e.g. table, chair) and the experimenter's actions. The problem requires using elements that previously seemed irrelevant. The inclusion of irrelevant elements in the representation of the problem is not a simple act of perception because solvers have to compare the experimenter's behavior (the number of fingers that he or she shows) and the problem's condition. The correct answer is the number of fingers that the experimenter shows before each question to the participant.

We also used two questionnaires:

1. The evaluation of the problem solving progress (hereinafter referred to as "Compass").

The questionnaire has nine dimensions based on Likert scales with 4 points. The "Compass" allows evaluating positive and negative emotions. It includes the Metcalfe scale (Metcalfe & Wiebe, 1987); questions about the impasse (Knoblich, Ohlsson, Haider, & Rhenius, 1999); questions used in the implicit learning studies (Sandberg, Timmermans, Overgaard, & Cleeremans, 2010).

2. The final questionnaire.

This questionnaire was filled after finding the solution. It is based on the Ellis's questionnaire (Ellis et al., 2011), but without scales to measure the problem series effects. The questionnaire allows comparing the objective parameters of a solution and its subjective ratings.

In both questionnaires, the answer options were: Absolutely NOT agree, Rather not agree, Rather agree, Absolutely agree.

The "Compass" questions (for participants was in Russian):

1. I am sure that I will solve the problem
2. I like the problem
3. I feel tense, it is hard for me
4. It seems to me that I understand the conditions correctly
5. It seems to me that I'm at an impasse right now
6. It seems to me that I'm close to a solution
7. It seems to me that I'm moving in the right direction
8. The problem disturbs, annoys, and upsets me
9. The problem fascinates, interests, and invigorates me.

The final questionnaire questions (for participants was in Russian):

1. When I understood the solution to the problem, I experienced "insight", an "Aha! experience"
2. I came to the solution step by step, making assumptions and logically checking them, as a result, the solution itself did not come as a surprise to me
3. At that moment, when I found a solution, I felt pleasure (from 1 – I did not receive pleasure, up to 4 – I felt expressed pleasure)
4. Finding a solution, I felt a surprise
5. I found this solution suddenly, it was unexpected

6. I was relieved to find this solution
7. I am sure that the solution I found is correct

Procedure

At the beginning of the experiment, the participant was outfitted with a wearable eye-tracker, SMI-ETG (ETG stands for Eye Tracking Glasses). The sample rate is 30 Hz binocular. The eye-tracker was calibrated with a 3-point method and was not calibrated during the experiment. The participant could move her or his head freely. After that, audio and video recording were turned on.

The problem was presented on a table before the participant. The participant solved the problem individually in the presence of the experimenter. After completing the preliminary procedures, the experimenter told the following instruction aloud (in Russian): "Sometimes something will happen on the table. You need to understand how many cars are in the garage. The garage may contain zero, one, two, three, four or five cars. After each change, I will ask you about the quantity of cars in the garage. You will need to give an answer. After that I will tell you, how many cars are actually in the garage. Let me know, when you understand the principle". During the instruction and throughout the experiment, the participant could ask questions and make any statements.

After the instruction, the participant was asked: "How many cars are in the garage?". The experimenter waited for the participant to respond. The participant had no constraints to ponder about the answer. Moreover, he or she could ask the experimenter about the problem. After the participant answered, the experimenter gave him or her feedback. It consisted of two parts: the correctness of the answer and the correct number of cars. Every offered solution was followed by a change in positions of the sticks. Thereafter, the participant was again asked to answer the experimenter's question about the quantity of cars.

The participant's process of the problem solving was interrupted by the "Compass" after five consecutive answers of the participant to the question "How many cars are in the garage?". At first, the participant was given instructions on how to complete the questionnaire, and she or he was told that the experiment would involve alternating between the two tasks. The instruction was (in Russian): "Read these statements and for each of them mark how much you agree with them". The "Compass" was printed on a Din A4 paper (twice on each page). Participants filled out the questionnaire with a pen. After that they continued solving the problem. The problem solving continued until a participant found a solution. When the problem was solved, the final questionnaire was provided. The instruction and presentation were the same as for the "Compass".

Design

For our research we used the design without an experimental manipulation (Single-Group Designs) in order to observe, classify and analyze relationships between emotions and representational change. We recorded the participants' behavior during the solution of the problem. The data consisted of video and audio (from eye-tracking glasses). We marked up the following types of events: a representation (correct/incorrect), the emotional pole (positive/negative), an interval (keep track how much time participants need to answer), and chaotic actions (the participant was acting randomly). All types of events (except intervals) were aggregated by sets and participants, and were translated to nominal (dichotomous nominal scale) variables and dummy coded (if events happen then 1, otherwise 0). The "Interval" (a ratio scale) was used to detect impasses. In the end we used next binomial variables: impasse (the set contained an impasse), representational change (during the set the representation changed), negative (the set contained a negative emotional response), positive (the set contained a positive emotional response), a chaotic action (the set contained a chaotic action), and a set before solution (the set number before solution – ordinal scale).

Data analysis

The data was marked in ELAN 5.8 (https://tla.mpi.nl/tools/tla-tools/elan/) for Windows and analyzed in RStudio (1.2.1335) using the R language version 3.6.1 (platform x86_64-w64-mingw32) for Windows on a laptop (Dell G5 15 5587). The markup consisted of selecting layers that contain time-bound events (start, end, duration). Each layer was marked separately and independently of other layers. We selected five layers. The layers refer to the analysis of video recordings in the ELAN. This is a method of grouping one kind of event together. Layers could be extracted simultaneously for all participants by the ELAN. Each layer will be a column. The rows include information about the start, end, and duration of every event and information about events that happened during this time.

The "Activity" layer included events related to the participant's activities:

1. Technical actions (putting on/removing the eye-tracker, preparing stimuli, etc.)
2. Instruction (the process of verbal presentation of instructions by the experimenter and the participant's questions about it)
3. The problem solution (actual problem solving processes)
4. Filling out the "Compass"
5. Filling out the final questionnaire.

The "Emotional pole" layer included two categories of the participant's emotions, negative and positive. The emotions were assessed by humans. The classification criteria were intonation, presence of laughter, screaming, sighing, etc.

The "Representation" layer contained two types of events: a correct representation and an incorrect representation. The representation was considered as incorrect until signs of the correct representation appeared. The moment of the first fixation on the experimenter's hand for more than 0.5 seconds was the criterion for the correct representation .

The "Chaotic Actions" layer contained one event: chaotic. It was distinguished by the presence of one of following features: using of words "Hmmm" [hmmm three] or "let" [let be five]; the answer about the quantity in the question form [Five?]; the answer with a laugh (provided that this is not the right answer at the end of solution); phrases such as "I do not understand", "I do not know", "What kind of logic is in this?", etc.; questions with the emotional reaction "How does it work?!", "What is happening?!", etc.

The "Interval" layer included one event: the answer. The event was defined as a time period from the moment when the experimenter finished the question, "How many cars are in the garage", to the moment when the participant began to answer.

The data collected from the layers by export mechanisms in the ELAN was presented in a table. Events from every layer were located in the corresponding columns (variables). Every five answers to the question “How many cars are in the garage?” were combined into one set for the analysis. The set had the beginning and end times and included all events that happened in the interval from the other layers. The analysis was performed on the basis of sets that aggregated all events during the set, i.e. a row of the table is one set. Each set had variables that reflected interesting events. Every variable was binomial.

The variable “Impasse” was classified based on the criteria used by G. Jones (Jones, 2003) and A. Fedor and colleagues (Fedor et al., 2015): the mean time and the standard deviation were calculated for each participant’s answer to the question about the number of cars (the answer time). Each answer time was compared with the mean time plus two standard deviations of the participant’s answer times. If the answer time was longer, then the answer was marked as an impasse answer. Hence, the set with at least one impasse was marked as the impasse set. Similar criteria were used for all variables.

The variable “Representational change” had “1” only in one set for each participant. It was the set with a gaze fixation on the experimenter’s hand for more than 0.5 seconds.

The variables “Negative” and “Positive” were treated identically: if the set contained emotions, then it received “1” (it received “0” in other cases).

The variable “Chaotic actions” contained the values of “1” and “0” as in the previous variables. The criteria for chaotic actions were the same as for the “Chaotic Actions” layer.

The variable “Sets before solution” contained the values of “1” and “0”. The data was filtered in such a way that the last two sets remained. The set with the solution was designated as “1”; the previous set was designated as “2”.

In order to test our predictions, we used logistic regression. All variables (dependent and independent) were binomial. We used a shift in the data for verifying that some events predict others. The shift means moving the data in the target column one row to the next. Everything else was left untouched. Thus, the event that was supposed to happen afterwards appeared in the same line as the event (or their combination) that should have preceded it. This analysis allows the use of logistic regression for the “after” data. However, the need to use sets may create a situation when in reality events occur one after another (as we predict in the model), but in the data they are in the same set. In this regard, we checked the predictions using models with and without a shift. Besides, in this study we collected data about filling the “Compass” and the final questionnaire. We did not analyze this data in the paper.

Results

Test of Prediction 1: Negative emotions arise after behavioral patterns of impasse and the participant still has the initial representation.

The result was not significant.

Test of Prediction 2: Negative emotions predict a chaotic activity.

Results of logistic regression with the predictor of presence/absence of negative emotions on the chance of a chaotic activity (with a shift) showed significant results for factor negative emotions (p = .038). Cox and Snell R^2 = .0883. Thus, chaotic activities appeared more frequently after negative emotions (see Table 1).

Results of logistic regression with the predictor of presence/absence of negative emotions on the chance of a chaotic activity (without a shift) showed significant results for the factor of negative emotions (p = .002). Cox and Snell R^2 = .1613. That means that chaotic activities appeared more frequently with negative emotions (see Table 2).

Test of Prediction 3: Positive emotions follow a representational change.

Prediction 3: Positive emotions follow a representational change (without a shift)

Results of logistic regression with the predictor of representational change on the chance of positive emotions (without a shift) showed significant results for the factor of representational change (p = .013). Cox and Snell R^2 = .0941. That means that representational changes appeared more frequently with positive emotions (see Table 3).

Test of Prediction 4: Positive emotions predict the awareness of a representational change.

Results of logistic regression with the predictor of the number of sets before a solution on the chance of positive emotions (without a shift) showed significant results for the factor

Table 1

Prediction 2: Negative Emotions Predict a Chaotic Activity (with a Shift)

Effect	Estimate	SE	95% CI		p
			LL	UL	
Intercept	−0.56	0.44	−1.48	0.29	.210
Negative emotions[a]	1.25	0.60	0.10	2.48	.038

Note. Degrees of Freedom = 47. CI = confidence interval; LL = lower limit; UL = upper limit.
[a] 0 = no, 1 = yes.

Table 2

Prediction 2: Negative Emotions Predict a Chaotic Activity (without a Shift)

Effect	Estimate	SE	95% CI		p
			LL	UL	
Intercept	−0.75	0.40	−1.59	0.02	.060
Negative emotions[a]	1.77	0.56	0.70	2.92	.002

Note. Degrees of Freedom = 60. CI = confidence interval; LL = lower limit; UL = upper limit.
[a] 0 = no, 1 = yes.

Table 3

Prediction 3: Positive Emotions Follow a Representational Change (without a Shift)

Effect	Estimate	SE	95% CI		p
			LL	UL	
Intercept	−1.49	0.37	−2.28	−0.82	< .001
Representation change[a]	1.65	0.67	0.35	3.00	.014

Note. Degrees of Freedom = 24. CI = confidence interval; LL = lower limit; UL = upper limit.
[a] 0 = no, 1 = yes.

of the number of sets before a solution (p = .003). Cox and Snell R^2 = .4237. That means that the set with a solution appeared more frequently with positive emotions (see Table 4).

Discussion

Experiment 1 was intended for testing a relationship between emotions and representations in insight problem solving. In order to test that we recorded the participants' solution process and marked up the recording. We highlighted many events that happened during the solution process. Afterwards we used logistic regression to test the correspondence between their order to our hypotheses.

Three out of four hypotheses were supported by our data. The results mean:

Negative emotions predict chaotic activities during solution. According to our model that means that negative emotions could switch the mode of the cognitive system. This can be the mechanism that switches "exploitation" to "exploration" in the model suggested by Fedor at al. (2015).

Positive emotions follow a representational change. According to the model, the result can be interpreted as a reaction to finding a promising representation or a search space. We suppose that positive emotions maintain the promising representation, and motivate the solver to exploit it. The data matches with the findings on the emergence of emotional response when a representational change occurs (Danek & Salvi, 2018). In addition to that, positive emotions can motivate participants to move in the direction that causes it (Danek et al., 2013) and to change their exploration mode to exploitation (Fedor et al., 2015).

Positive emotions predict solution awareness. It means that emotions are markers that detect relevant representation and start the process of exploitation and awareness. The results correspond to findings on emotions preceding awareness (Tikhomirov, 1983; Valueva et al., 2016).

Thus, only the first assumption (negative emotions are reactions to changes in cognitive activity (impasse)) was not supported by the data. The possible reason for this result could be the data is insufficient to detect the participant's emotions (negative emotions in particular). Besides it could be that the intervals selected for analysis were too long and relationships between emotions and cognitions were not visible due to the events from different solution stages being grouped together.

Table 4

Prediction 4: Positive Emotions Predict the Awareness of a Representational Change (without a Shift)

Effect	Estimate	SE	95% CI		p
			LL	UL	
Intercept	4.89	1.68	1.92	8.73	.004
Sets before solution[a]	−3.69	1.23	−6.81	−1.61	.003

Note. Degrees of Freedom = 24. CI = confidence interval; LL = lower limit; UL = upper limit.

[a] 1 = set when the solution was found, 2 = 1 set before the solution.

We made an attempt at altering two parameters (data for emotion detection and the duration of the answer time interval) in Experiment 2, as we believe that the parameters greatly affected the results.

Experiment 2

The main purpose of Experiment 2 was the same as for Experiment 1, to investigate the relationship between emotions and representation. However, Experiment 2 was aimed to replicate the results of Experiment 1, and to check the adequacy of the methods of collecting and analyzing the data. The other difference was the use of a front video to record the participants' faces and bodies (necessary for getting more information about their emotional experiences), as the use of eye-tracker gives information only about verbal production and visible gestures. It could be the reason why we failed to detect the emotions of the participants during the solution, and the results obtained were less accurate. Furthermore, we reduced time intervals for answering. In Experiment 2 sets had to be shorter and more frequent, as, in our opinion, Prediction 1 was not supported by the evidence, because the time interval was too long, and the events that belonged to different solution stages were mixed.

We used Zakharov's problem as an insight problem (Zakharov, 1963). The problem has many elements, and the participant can come up with many ideas about the relationship among problem elements. These ideas are often easy to verbalize. It enables participants to provide a large number of verbal reports on the solution processes. This problem feature is especially important, because it allows evaluating the representational change in comparison with the participants' subjective feelings. Verbal reports are useful for checking our method for the subjective signs of a representational change.

Method

Participants

There were 22 participants (15 female and 7 male), aged 18–28 (M = 20.68, SD = 2.85). The majority of the sample consisted of undergraduate and graduate students at Yaroslavl State University. All participants were tested individually, took part voluntarily, and were not paid for their participation. All participants provided a written informed consent. The consent form included questions about their consent to be recorded and permission for ways of using recordings (a multiple choice).

Stimuli

We used Zakharov's problem that requires a rearrangement of eight figures so that all of them are in the correct places. Numbered figures of two different colors (red and violet), two different shapes (circle and square) and two different sizes (big and small) are placed in squares of the same size, one figure in each square. The squares are grouped by four, with a small distance between them. The initial position of the figures was the same for all participants (see Figure 2). Figures can be interchanged only in pairs, i.e. when a chosen figure has been placed in an occupied square, a figure from the occupied square will be moved to the square from where the chosen figure was taken. After each move, feedback about the number of correctly placed figures is given. The search for the problem's rule for grouping figures is initially provoked in the problem by the figures having multiple features. However, there is no rule in the problem that can be found by observing features of the figures. In order to solve problem, it is necessary to focus only on the feedback. The correct answer is chosen in such a way that it does not contain any rule: figures with the numbers 1, 5, 7, and 8 should be in the left four squares; figures with the numbers 2, 3, 4, and 6 should be in the right squares. The order of figures does not matter. The study used the same questionnaires as in Experiment 1.

Procedure

Firstly, each participant was provided with a consent form. After his or her written consent was provided, the script on Python was launched for the participant. The participant got the instruction on the computer screen (in Russian): "You will see the space similar to the one below. Some of the figures are not in places that the experimenter intended. You will need to move figures with the mouse cursor in such a way that the arrangement conceived by the experimenter is restored. After each move, the number of correctly placed figures will be shown at the top of the screen. Every third move the problem solving will be suspended and you will need to tell the camera why you made these moves. After that you should press the SPACE to continue the problem solving. To return to the instruction, press F1. You will need to fill in a questionnaire after every 15th move . At the end of the solution you will be presented with a final questionnaire".

The instruction was accompanied by a video. The video contained several seconds of interactions with problem elements (numbers and colors were different from real problems) and the location of the feedback zone was circled in red. After the participant was certain that she or he understood the instruction, she or he clicked on the space button on the keyboard and started the problem solving. The participant moved the figures with mouse. Every third move, the participant reported aloud reasons for her or his actions; every 15th move he or she filled the "Compass" (it was presented on the computer screen).

Figure 2

Zakharov's Problem Presented to the Participants

The time limit for the problem was 25 minutes. The solution process was interrupted when the time reached 25 minutes. If the participant found the correct answer before that, a computer program automatically reported it and showed to the participant a message about their success. Then the participant explained to the experimenter their solution to the problem. Many participants did not consider use of the feedback as a relevant hint. They often said "I do not know how I solved the problem". Such participants were additionally questioned about the solution principle. The questions were necessary to determine whether participants solved the problem by chance or did not think that the use of feedback was the right thing to do. After that, they filled in the final questionnaire.

The computer screen and the participant's face and body were recorded simultaneously using one of three laptops (Dell G5 15 5587, Asus K50I, or Lenovo IdeaPad 330-15ARR). We also used one of the webcams, Logitech C270, Logitech QuickCam B500, or a webcam in the Asus K50I laptop.

Design

The design was the same as for Experiment 1.

Data analysis

Analysis and marking were done using the same hardware and software as in Experiment 1.

The layers "Activity" and "Emotional pole" included the same events as in Experiment 1. The "Representation" layer was changed. In Experiment 2 the representation was assessed by the participants' verbal reports. They spoke after every third move. Types of features that participants thought as the most important for solving the problem were added to the layer (numbers, sizes, colors, forms or a mix of the aforementioned). The "Chaotic action" layer was merged with "Representation" and was detected by verbal reports. If the participants said that they were doing moves randomly, it was marked as a "chaotic action". Since Zakharov's problem permits many types of representations, we added the layer "Representation change". It includes two types of events: "changed" (if the previous representation did not match with the current one) and "not changed" (if they matched). The first representation was always marked as "not changed".

The set in Experiment 2 varied from that in Experiment 1; it included 3 moves in place of 5 answers. Variables for analysis were the same as in Experiment 1. Due to technical difficulties the impasse was distinguished by the length of the set in place of the length of every single move, i.e. length of the set was compared to the mean of the sets length plus 2 sd of the sets length. As in Experiment 1, the comparison was individual for every participant. As in Experiment 1, logistic regression was used for analysis .

Results

Test of Prediction 1: Negative emotions arise after behavioral patterns of impasse and the participant still has the initial representation.

Results of logistic regression with the predictors of presence/absence of impasse, representation change and their interactions on the chance of negative emotions (without a shift) showed significant results for the factor of impasse (p = .002). Cox and Snell R^2 = .0223. That means that negative emotions more frequently appeared in an impasse (see Table 5).

For Predictions 2, 3, and 4, the results were not significant. There was an inconsistency in our data. We want to check a hypothesis about it and discuss it later in the general discussion. In order to investigate the cause of the inconsistency of results in two problems, we compared the time of the first impasse in both experiments. Comparison of the mean time of the first impasse revealed that the time for Zakharov's problem (M = 428.7, SD = 357.1) was significantly higher than the time for the problem "How many cars are in the garage?" (M = 139.3, SD = 150), t (25) = −2.42, p = .023, r = .44.

Discussion

In Experiment 2 we obtained results that are opposite to Experiment 1. The results support Prediction 1 on the relationship between negative emotions and impasse. According to our model, negative emotions are markers signaling about futility of representation; they start a switch from the mode of exploitation to the mode of exploration. In the exploration mode participants try to find a promising representation. However, the remaining three predictions were not supported. This contradicts the results of Experiment 1. We think that the root of the inconsistency could have been caused by the difference between the methods and the problems. Regarding the method it is possible that the detection of a representational change was less accurate without an eye-tracker. We could only use participants' verbal reports. Verbal reports could be significantly slower (as reports were provided after a change) and less accurate (participants could forget something or may have failed to verbalize the changes) in order to reliably detect a representational change. Differences among problems will be considered in the general discussion. For now, we can only point out that in the problem "How many cars are in the garage?" there are only two stable representations: the answer is determined by the position of matchsticks; the answer is the number of fingers shown by the experimenter. These representations differ considerably. In Zakharov's problem there are several similarly stable

Table 5

Prediction 1: Negative Emotions Arise after Behavioral Patterns of Impasse and the Participant Still Has the Initial Representation (without a Shift)

Effect	Estimate	SE	95% CI		*p*
			LL	UL	
Intercept	−1.57	0.12	−1.82	−1.33	< .001
Impasse[a]	1.57	0.52	0.55	2.60	.02
Representation change[b]	−0.21	0.21	−0.63	0.19	.031
Impasse: Representation change	1.31	1.28	−1.00	4.45	.30

Note. Degrees of Freedom = 757. CI = confidence interval; LL = lower limit; UL = upper limit.
[a] 0 = no, 1 = yes, [b] 0 = no, 1 = yes.

representations: colors, sizes, and forms of the figures, and several sequences of the numbers. Solvers may be unable to distinguish representations when there are many similar representations that results in their inability to report a representational change.

General discussion

In the study we tested a linguistic method of analyzing multimodal corpus for insight problem solving research. Unfortunately, the results do not allow us to say that our hypotheses were fully maintained. Each of the hypotheses found support only in one of the two problems used (2, 3, and 4, in the problem "How many cars are in the garage?" and 1, in Zakharov' problem). This may be due to the nature of the problems used and the features of recording the participants' emotions and cognitive activity as they were solving the problems. In particular, in the problem of "How many cars are in the garage?", the use of eye-tracking glasses in the experiment hinders the recording of emotions. In Zakharov's problem an unambiguous interpretation of changes in representations cause difficulty. Despite this, we believe that the data obtained shows the heuristic potential of the model being tested, and more reliable data can be obtained in the future, provided that problems are selected that allow us to reliably record the parameters of the solver's cognitive activity and emotions. Further, the results are described in more detail.

Discussion of the Results in the Context of the Model Being Tested

The first prediction: negative emotions arise after behavioral patterns of impasse and the participant still has the initial representation.

In Zakharov's problem the impasse predicts the appearance of negative emotions. This corresponds to our expectations and can be explained by the signaling function of negative emotions as they notify of the futility of the current representation for a solution. These findings match with our previous results (Markina et al., 2018) and with those of our colleagues (Fedor et al., 2015).

The second prediction: negative emotions predict the appearance of a chaotic activity. As the results of analyzing the solutions to the problem "How many cars are in the garage?" demonstrate, negative emotions predict a transition to a chaotic search. This and the previous prediction are consistent with the model of overcoming the impasse proposed by S. Ohlsson (Ohlsson, 2011). Ohlsson says that a stable initial representation would be destroyed by incoming negative feedback. After the destruction an automatic reconfiguration of the elements happens. The negative feedback can be consciously experienced in the form of negative emotional responses. Also, the result can be correlated with the data that we obtained earlier: the initial representation is destroyed by disabling control at the stage of an impasse. A negative emotional experience can trigger the destruction of a representation (Markina et al., 2018).

The third prediction: positive emotions follow a representational change. Positive emotions follow the change in a representation in the problem "How many cars are in the garage?". We interpret this as an indication of a new perspective research development (the discovery of new features in the problem space). Positive emotions are markers that show a promising direction. The data is consistent with a range of works that substantiate the regulatory and signaling functions of emotions in general and of the Aha! Experience, in particular, in problem solving (Valueva et al., 2016; Tikhomirov, 1983; Schwarz, 2011). The Aha! experience can also be associated with a suddenness of a representational change (Danek & Salvi, 2018).

The fourth prediction: positive emotions predict the awareness of a representational change. Positive responses predict the awareness of the answer in the problem "How many cars are in the garage?". We interpret this as an emotional marking of the right solution. The data is consistent with the results of a number of works that prove the signaling role of the Aha! experience indicating the correct answer (Valueva et al., 2016; Tikhomirov, 1983) that enables the differentiation between the right solution and a wrong one (Danek & Wiley, 2017; Danek, Williams, & Wiley, 2020). In addition to that evaluations of the scales by which an Aha! experience can be measured related to the correctness of the answer (Laukkonen, Kaveladze, Tangen, & Schooler, 2020).

Discussion about Possible Side Effects of the Research Method on the Structure of Results and Limitations of the Method

We got contradicting results. The most probable reason for the results may have been the varying internal structure of the problems. Besides, this could be explained by different ways of recording the participants' cognitive activity. For example, the problem "How many cars are in the garage?" gives the opportunity to track more subtle changes in the cognitive activity, because the eye-tracking data was available in this problem. However, in Zakharov's problem the recording of facial expression was available. Therefore, the emotional responses could be assessed more accurately.

We analyzed the structure of the results and compared it with the features of the problems and the methods of registering the participants' activity. The experiment that employed Zakharov's problem (Experiment 2) partially corroborated the hypothesis of negative emotions accompanying the behavioral patterns of impasse (an increased solution time). The absence of negative emotions in the next set may indicate that the set size of the problem was too large (3 moves). The observable emotions appear and disappear very quickly, and a large set size leads to a situation where emotions are located within the one set. Besides, after every set participants were asked to talk about their actions. This could reduce the power of emotion, and consequently emotions could not be detected. Experiment 1 that used the problem "How many cars are in the garage?" found support for all other hypotheses (negative emotions precede the chaotic activity; positive emotions follow the representational change (only for the simultaneous variant); positive emotions occur simultaneously with (do not precede) the awareness of a representational change). For the problem, we observe a phenomenon similar to the previous problem. The prediction of the time separation between emotions and the representational change was not confirmed. Probably, it is also associated with too large set size for the analysis (5 moves). Emotional reaction arises faster and continues for a relatively short time. It indirectly indicates the informational role of emotions. The solver has emotions for a short time, only during the period when a cognitive activity changes. Thus, emotions are rather associated with the solution and not with background emotional feelings.

Why does Zakharov's problem have negative emotions that are associated with the impasse, but why are the remaining model predictions not observed? Firstly, the number of parameters for a solver to operate in Zakharov's problem is higher than in the "How many cars are in the garage?" problem (8 figures, each having four attributes, color, size, form, and number). It makes the problem more uncertain and incomprehensible for the participant. Secondly, the participant has more freedom to manipulate the figures. In Zakharov's problem, participants can test their hypotheses when they want, while in the "How many cars are in the garage?" participants only interpret the experimenter's manipulations. Thus, Zakharov's problem is more complex and allows the solver to be more active. Zakharov's problem is important to detect the incorrect representation of the problem. An active manipulation with the elements of the problem allows a detection of errors in the problem's representation. Negative emotions perform the function of detection, when they accompany an impasse. We observe a similar picture in the results obtained: in Zakharov's problem, the impasse predicts negative emotions, but in the problem "How many cars are in the garage?" it does not. Thirdly, in Zakharov's problem the impasse appears later (t (25) = −2.42, p = .023, r = .44). In this case, negative emotions may be more distinct through a cumulative effect, and, as a result, they are better detected. The emotions may be presented in the problem "How many cars are in the garage?", but it is hard to detect as the emotions are weak. Besides, in Zakharov's problem, the video recordings of the participants' faces made the detection and classification of emotions more precise.

But why are the other three predictions confirmed only for the problem "How many cars are in the garage?" In our opinion, the data availability about the participants' search activity must play the most important role in it. In the problem "How many cars are in the garage?" events can be detected both through the participants' video recordings and using the eye-tracking data. It enables an accurate identification of processes of the chaotic activity and representational change; as the result, the data demonstrates confirmation of the model predictions. In Zakharov's problem, we had to rely on less reliable criteria in order to detect problem solving events.

Thus, the structure of the obtained data rather indicates limitations of the research method than the difference of the problems used. Unfortunately, the advantages of eye-tracking (revealing the participant's information search activity) and recordings of the solver's face (revealing emotions) are incompatible. It happened because we used a wearable eye-tracker that covers half of the person's face. Perhaps, it is worth considering ways of finding other technical solutions to record participants' action for further work. There is another method limitation that could affect the accuracy of the data markup. We identified the impasse only using one criterion (an increase of the solution time). But it is possible to use other criteria. For example, repetitive actions in the problem solving could be a good criterion. The insufficiently accurate detection of the impasse could affect the number of impasses. In our data the average number of the impasses was about one per solution (M = 0.85, SD = 0.55 for the problem "How many cars are in the garage?"; M = 0.91, SD = 0.61 for Zakharov's problem). It complicates the verification of the model predictions about the cyclic nature of solution.

Thus, if our ideas about the nature of the current result deviations (as compared to the expected ones) are correct, we can tentatively believe that the model is confirmed (in principle). Of course, the proposed model requires further verification. It is especially true for assumptions on the cyclical nature of problem solving (at the moment there are few solutions in the corpora with several impasses: 4 out of 36). Probably the assumptions on the cyclical nature can be correctly investigated after a sufficient amount of multimodal recordings with multiple impasses has been accumulated. And in addition to that, it is still probable that the relationship between emotion and insight may depend on the problem.

Conclusion

We obtained data that allows a tentative confirmation of the following predictions of the model of emotional regulation of representational change.

1. The insight solution is accompanied by emotional responses that control the processes of a representational change. Negative emotions (the feeling of an impasse) are a reaction to the lack of problem solving progress due to the use of the initial representation. Positive emotions (the Aha! experience) are a reaction to randomly performed actions that advance the solver significantly closer to the answer.

2. These emotions precede the awareness of a solution. They motivate to move in the problem space following the detected path.

Moreover, we showed the use of the linguistic method for analyzing a multimodal corpus of insight problem solving. The method looks promising for further research. The method provides for the detailed accumulation of the phenomenology in insight problem solving and for a base suitable for testing post hoc hypotheses (including further studies performed by other researchers).

References

Beeftink, F., van Eerde, W., & Rutte, C. G. (2008). The effect of interruptions and breaks on insight and impasses: do you need a break right now? *Creativity Research Journal, 20*, 358–364. doi:10.1080/10400410802391314

Bowden, E. M., & Jung-Beeman, M. (2003). Aha! Insight experience correlates with solution activation in the right hemisphere. *Psychonomic Bulletin and Review, 10*(3), 730–737.

Danek, A. H. (2018). Magic tricks, sudden restructuring, and the Aha! experience: A new model of nonmonotonic problem solving. In F. Vallee-Tourangeau (Ed.), *Insight: On the origins of new ideas* (pp. 51–78). London: Routledge.

Danek, A. H., Fraps, T., von Müller, A., Grothe, B., & Öllinger, M. (2013). Aha! experiences leave a mark: Facilitated recall of insight solutions. *Psychological Research, 77*(5), 659–669. doi:10.1007/s00426-012-0454-8

Danek, A. H., & Salvi, C. (2018). Moment of truth: Why Aha! Experiences are correct. *The Journal of Creative Behavior, 22*(4), 443–460. doi:10.1002/jocb.380

Danek, A. H., & Wiley, J. (2017). What about false insights? Deconstructing the Aha! experience along its multiple dimensions for correct and incorrect solutions separately. *Frontiers in Psychology, 7*(2077), 1–14. doi:10.3389/fpsyg.2016.02077

Danek, A. H., Wiley, J., & Öllinger, M. (2016). Solving classical insight problems without Aha! experience: 9 Dot, 8 Coin, and Matchstick Arithmetic Problems. *The Journal of Problem Solving, 9*(1), 47–57. doi:10.7771/1932-6246.1183

Danek, A. H., Williams, J., & Wiley, J. (2020). Closing the gap: connecting sudden representational change to the subjective Aha! experience in insightful problem solving. *Psychological Research, 84*, 111–119. doi:10.1007/s00426-018-0977-8

Duncker, K. (1945). On problem-solving. *Psychological Monographs, 58*(5), i–113. doi:10.1037/h0093599

Ellis, J. J., Glaholt, M. G., & Reingold, E. M. (2011). Eye movements reveal solution knowledge prior to insight. *Consciousness and Cognition: An International Journal, 20*(3), 768–776. doi:10.1016/j.concog.2010.12.007

Fedor, A., Szathmáry, E., & Öllinger, M. (2015). Problem solving stages in the five square problem. *Frontiers in Psychology, 6*, 1050. doi:10.3389/fpsyg.2015.01050

Jones, G. (2003). Testing two cognitive theories of insight. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(5), 1017–1027. doi:10.1037/0278-7393.29.5.1017

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., ... Kounios, J. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biology, 2*(4), e97. doi:10.1371/journal.pbio.0020097

Knoblich, G., Ohlsson, S., Haider, H., & Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(6), 1534–1555. doi:10.1037/0278-7393.25.6.1534

Knoblich, G., Ohlsson, S., & Raney, G. E. (2001). An eye movement study of insight problem solving. *Memory and Cognition, 29*, 1000–1009. doi:10.3758/BF03195762

Köhler, W. (1972). *The task of Gestalt psychology.* Princeton, NJ: Princeton University Press.

Kounios, J., & Beeman, M. (2014). The cognitive neuroscience of insight. *Annual Review of Psychology, 65*, 71–93.

Laukkonen, R. E., Kaveladze, B. T., Tangen, J. M., & Schooler, J. W. (2020). The dark side of Eureka: Artificially induced Aha moments make facts feel true. *Cognition, 196*, 104122. doi:10.1016/j.cognition.2019.104122

Lausberg, H., & Sloetjes, H. (2009). Coding gestural behavior with the NEUROGES-ELAN system. *Behavior Research Methods, 41*(3), 841–849. doi:10.3758/BRM.41.3.841.

Makarov, I. N., & Vladimirov, I. Yu. (2019). Multimodal corpus of nsight solutions. *Abstracts of the Psychonomic Society, 24*, 277–278

Markina, P. N., Makarov, I. N., & Vladimirov, I. Yu. (2018). Osobennosti pererabotki informatsii na stadii tupika pri reshenii insaitnoi zadachi [Information processing at the impasse stage when solving an insight problem]. *Teoreticheskaya i Eksperimental'naya Psikhologiya [Theoretical and Experimental Psychology], 11*(2), 34–43. (in Russian)

Metcalfe, J., & Wiebe, D. (1987). Intuition in insight and noninsight problem solving. *Memory and Cognition, 15*, 238–246.

Newell, A., & Simon, H. A. (1972). *Human problem solving.* Englewood Cliffs, NJ: Prentice-Hall.

Ohlsson, S. (1992). Information-processing explanations of insight and related phenomena. In M. T. Keane and K. J. Gilhooly (Eds.), *Advances in the psychology of thinking* (pp. 1–44). New York: Harvester-Wheatsheaf.

Ohlsson, S. (2011). *Deep learning. How the mind overrides experience*. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511780295

Öllinger, M., Jones, G., Faber, A. H., & Knoblich, G. (2013). Cognitive mechanisms of insight: the role of heuristics and representational change in solving the eight-coin problem. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 931–939. doi:10.1037/a0029194

Öllinger, M., Jones, G., & Knoblich, G. (2014). The dynamics of search, impasse, and representational change provide a coherent explanation of difficulty in the nine-dot problem. *Psychological Research, 78*, 266–275. doi:10.1007/s00426-013-0494-8

Ponomarev, Ya. A. (1976). *Psikhologiya tvorchestva* [The Psychology of Creativity]. Moscow: Nauka. (in Russian)

Sandberg, K., Timmermans, B., Overgaard, M., & Cleeremans, A. (2010). Measuring consciousness: is one measure better than the other? *Consciousness and Cognition, 19*(4), 1069–1078.

Schwarz, N. (2011). Feelings-as-information theory. In P. A. M. Van Lange, A. W. Kruglanski, & E. T. Higgins (Eds.), *Handbook of theories of social psychology* (pp. 289–308). Sage Publications Ltd. doi:10.4135/9781446249215.n15

Tikhomirov, O. K. (1983). Informal heuristic principles of motivation and emotion in human problem solving. In R. Groner, M. Groner & W. F. Bischof (Eds.), *Methods of heuristics* (pp. 153–170). Hillsdale, NJ: Lawrence Erlbaum.

Valueva, E., Lapteva, E., & Ushakov, D. (2016). Aha-cueing in problem solving. *Learning and Individual Differences, 52*, 204–208. doi:10.1016/j.lindif.2016.02.003

Wallas, G. (1926). *The art of thought*. London, UK: Jonathan Cape.

Zakharov, A. N. (1963). Ob ispol'zovanii informatsii v zadachax, reshaemykx s pomoshch'yu prob [On the information use in problems solved by trial]. In N. I. Zhinkin & F. N. Shemyakin (Eds.), *Myshlenie i rech* [Thinking and language] (pp. 47–65). Moscow: APN SSSR. (in Russian)

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От «Хммм...» до «Ага!»: эмоциональный мониторинг изменения репрезентации

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Резюме

Существует две основных парадигмы изучения инсайта: изучение эмоциональных реакций на решение («Ага-реакция») и изучение изменения репрезентации. Связь между данными парадигмами можно найти, поняв, какие функции они выполняют относительно друг друга. Часто при изучении инсайта используют короткие задачи (тест отдаленных ассоциаций, анаграммы), которые могут быть решены за короткое время и которые имеют очень сходную структуру. Мы полагаем, что такие дизайны исследования часто ведут к тому, что в исследовании пропускаются момент тупика и изменение первоначальной репрезентации задачного пространства. Используя заимствованный из лингвистики метод мультимодальных корпусов для анализа отдельных решений, мы получили частичное подтверждение ключевых положений модели эмоциональной регуляции смены репрезентации как механизма инсайтного решения. Согласно модели процесс инсайтного решения сопровождается эмоциональной регуляцией процесса изменения репрезентации. Чувство тупика является реакцией на отсутствие продвижения к решению. «Ага-реакция» появляется вслед за выполнением действий, которые существенно приближают субъекта к решению задачи. Мы полагаем, что эти эмоции переживаются до того, как решение достигает сознания, и мотивируют к изменению пространства поиска в соответствующем направлении. Предложенная нами модель является развитием идей Я.А. Пономарева относительно роли эмоций в регуляции инсайтного решения и модели М. Олингера с коллегами, описывающей фазы инсайтного решения.

Ключевые слова: инсайт, решение задач, тупик, эмоции, мультимодальный лингвистический корпус.

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