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The influence of inner speech suppression on the insight problem solving

Filip Jendrol [1], Marián Špajdel [1]

[1] Department of Psychology, Faculty of Philosophy and Arts, University of Trnava, Hornopotočná 23, 918 43 Trnava, Slovak Republic.

Correspondence to: Filip Jendrol, Department of Psychology, Faculty of Philosophy and Arts, University of Trnava, Hornopotočná 23, 918 43 Trnava, Slovak Republic.
TEL: +421944755251, E-MAIL: f.jendrol@gmail.com

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Abstract

OBJECTIVE: Inner speech suppression hinders solution of verbal but enhances solution of visual insight problems. We aimed to find out whether it hinders the solution of matchstick problems. Participant's eye movements were analyzed to examine in detail possible effects on solution process characteristics proposed by the Representational change theory (RCT) - initial representation of the problem, impasse, and restructuration.
DESIGN: 60 participants were randomly assigned to either experimental or control group. Both groups were solving two matchstick problems of different difficulty in random order. Inner speech restriction in experimental group was induced by concurrent listening to repetitive series of changing letters. Eye movements were recorded via eye tracker.
RESULTS: In line with the RCT, we found significant difference between solution times for easier and harder problem. Listening to irrelevant speech did not affect solution rates or times. Considering eye movements, only participant's initial representation of the problems corresponded to the RCT. No effects of inner speech suppression on examined eye movement patterns were observed.
CONCLUSIONS: Our study extends knowledge about the role of inner speech in problem solving to previously unexamined task. Results suggest that matchstick problems are partially solved by different processes than either verbal or classic visual insight problems, since their solution is unaffected by inner speech suppression. Inclusion of eyetracking methods in future research examining effect of inner speech on problem solving could provide more nuanced picture of its functions.

Introduction

Inner speech

Inner speech can be defined as: *"the subjective experience of language in the absence of overt and audible articulation."* (Alderson-Day & Fernyhough 2015, p. 931). It accounts for about 26% of people's conscious experience (Heavey & Hurlburt 2008) and probably serves a number of purposes. Experimental work on the verbal interference effect points to importance of inner speech mainly for memory, categorization, and executive functions (Nedergaard *et al.* 2023), but self-report methods indicate it could be also used for motivation, self-reflection or daydreaming... (Morin *et al.* 2011). Two theories of its functions are most discussed. In the Baddeley and Hitch's working memory model, it is a part of the phonological loop, which supports conscious representation of verbal material (e.g. phone number) (Baddeley 2012). In contrast, Vygotsky (1997, 2012) considered it a tool for the regulation of mental activity. According to him, higher mental processes during the ontogenesis firstly appear as a part of social interactions between the child and other persons, that influence each other by means of speech. Later, these interactions are becoming internalized, so the mature individual eventually influence himself by means of inner speech.

Vygotsky's ideas were further elaborated in the Fernyhough's (1996, 2009) dialogical thinking framework. Fernyhough emphasized that alongside with social interactions, the process of mutual exchange of different semiotically represented perspectives of their participants is becoming internalized as well. Consequently, the mature mind can flexibly take on different perspectives on reality. This occurs through an inner dialogue, typically mediated by inner speech. Importantly, one of the proposed functions of this form of thinking is open, creative problem solving.

Insight problems

Problems can be divided into well (analytic) and ill-defined (Davidson & Sternberg 2003). In the case of well-defined problems (e.g., chess), the solver can establish an adequate representation of the initial and goal states, and of possible actions - he "just" must search through them. However, facing ill-defined problems (e.g., choice of dissertation topic), it is difficult to imagine an appropriate goal, initial state, or available resources. Insight problems (Fig. 1) are a simplified class of ill-defined problems (DeYoung *et al.* 2008), characterized by "Aha!" experience – sudden, surprising discovery of the solution (Laukkonen *et al.* 2021). Several theories that attempts to explain their solution process can be broadly classified into special-process and business-as-usual approaches (Ball *et al.* 2015; Ball & Stevens 2009; Bowden *et al.* 2005; Gilhooly *et al.* 2010).

The business-as-usual approaches assume that insight problems are solved by conscious processes, also important for solving analytical problems. An example is progress monitoring theory, according to which participants are distracted from the solution path by the application of inappropriate heuristics, when they attempt to minimize the distance between the current state and the goal state. Solution requires the realization that the remaining actions do not allow adequate progress and that novel moves must be sought (MacGregor *et al.* 2001). Special-process approaches assume that insight problems are solved by implicit operations (e.g., relaxation of self-imposed constraints), different from those typically needed for solving analytic problems. An example is the representational change theory, according to which insight problems mislead the solver into applying conventional knowledge and forming an inappropriate representation of the problem, which has to be changed (Knoblich *et al.* 2001). Several studies point out that successful solution of insight problems depends on the processes postulated by both theories (Jones 2003; Öllinger *et al.* 2014). In some cases, however, only one of them may be relevant – Öllinger *et al.* (2006) found no support for progress monitoring theory in explaining the difficulty of matchstick arithmetic problems.

The function of inner speech in insight problem solving

Inner speech possibly is important for insight problem solving according to Ball and Stevens (2009). They found that the suppression of subvocal articulation by a secondary verbal task impairs the ability to solve the compound remote associates (CRAT). CRAT are considered to be a simplified type of insight problems, characterized by similar properties (Bowden *et al.* 2005), whereas success in solving them correlates with the ability to solve classic insight problems (Schooler & Melcher 1995). Ball and Stevens (2009) interpret the results as a support for the business-as-usual approach.

In contrast, according to Ball *et al.* (2015) the restriction of inner speech improves insight problem solving. The authors interpret the results in favor of a special-process approach and suggest that the restriction of conscious verbal thinking provides more opportunities for implicit processes, important for insight. However, they used only visual insight problems, thus, restricting inner speech could also make solving insight problems more difficult if they are of verbal and easier if they are of visual nature. This interpretation is supported by the work of Gilhooly *et al.* (2010), who found that the overt verbalization of the solution process (verbal overshadowing) impairs solving visual but not verbal problems – regardless of whether they are insight or analytic.

We further argue that the assumption that inner speech participates in insight problem solving has also theoretical justification in the above mentioned Fernyhough's (1996, 2009) dialogical thinking framework. This framework might also offer an alternative explanation for Ball and Stevens' (2009) findings – restricting

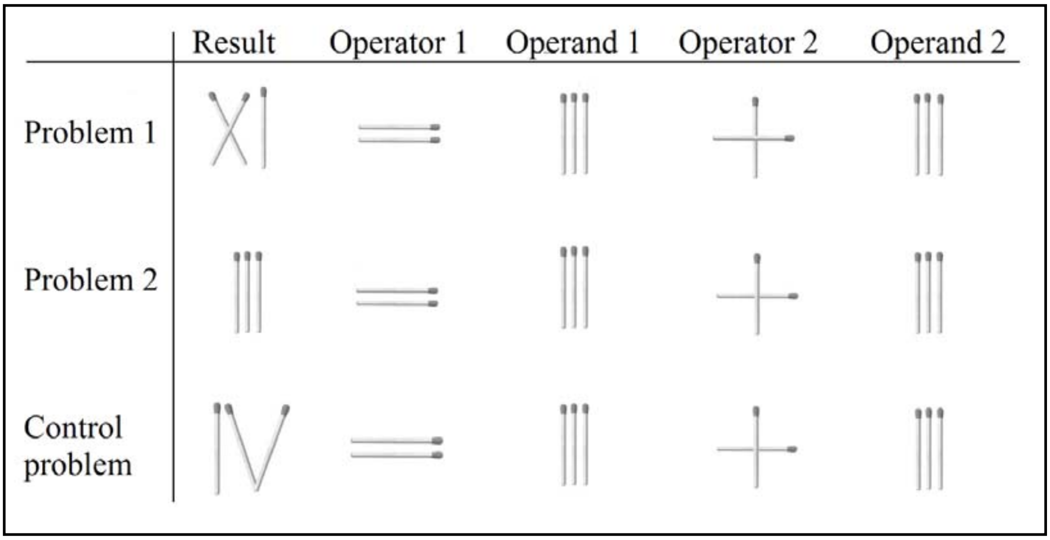

Fig. 1. Elements of used insight problems

inner speech may impair insight problem solving performance because inner speech is needed to mediate dialogic interactions, within which alternative representations of the problem are being created. In this case, insight problem solving would be, in line with business-as-usual approaches, rather a conscious process. However, inner speech would mediate processes that are needed rather specifically for solving ill-defined and not analytic problems.

Aim of the current study

Our study takes the form of a between-subject experiment examining the effect of inner speech restriction on the solution of matchstick arithmetic problems. We aimed to investigate 3 questions: 1.) Can previous findings about the negative impact of inner speech restriction on the solution of CRAT (Ball & Stevens 2009) be generalized to another type of insight problems, presented in a symbolic form? 2.) If inner speech restriction has a negative impact on insight problem solving, is it a consequence of a disruption of processes producing the representational change? According to Knoblich *et al.* (1999, 2001), a key part of solving matchstick arithmetic problems is a change of their representation. However, the mere negative impact of inner speech restriction on solving these problems would not rule out the possibility, that the solution depends also on some other processes - and that the inner speech restriction cause rather their disruption. Therefore, we use 2 different matchstick arithmetic problems (Fig. 1), which should be virtually identical except for the difficulty to achieve the representational change. If inner speech is involved in the representational change, its restriction should result in a greater performance deterioration for the harder than for the easier problem. Otherwise, the performance deterioration should be identical for both problems. 3.) How does the inner speech restriction affect the solution process? Previous studies focused on the effect of inner speech restriction on the performance levels. However, insight problem solving probably consists of several stages, characterized by specific eye movement patterns (Knoblich *et al.* 2001): A.) Inappropriate initial representation of the problem, B.) Stage of impasse, caused by exhaustion of possible moves, C.) Representational change and solution finding. We aim to explore the impact of the inner speech restriction on each of these stages.

Methods

Participants

Sixty psychology students (45 females) with a mean age of 19 years (SD = 1.53) took part in the study. Participants were randomly assigned to the control group and to the experimental group. All subjects participated voluntarily, without compensation, and signed an informed consent. Exclusion criteria were: Unfamiliarity with Roman numerals, previous experience with the problems used, and uncorrected visual impairment. Data from 4 subjects were excluded due to lack of sufficient information for an analysis of their eye movements.

Insight problems

The insight problems were adapted from studies by Knoblich *et al.* (1999, 2001). In each problem (Fig. 1), the participant's task is to correct the equation by changing the position of one matchstick so that it is mathematically correct. Performance was measured by solution rates and times. Participants had max. 5 min. to solve each problem. If problem was not solved, the solution time was replaced by the max. time limit.

Problem 1 required representational change in the sense of the decomposition of the tight chunk (i.e., meaningful X into meaningless \ and /). Problem 2 was more difficult - representational change consists in realizing that it is possible to manipulate the sign as

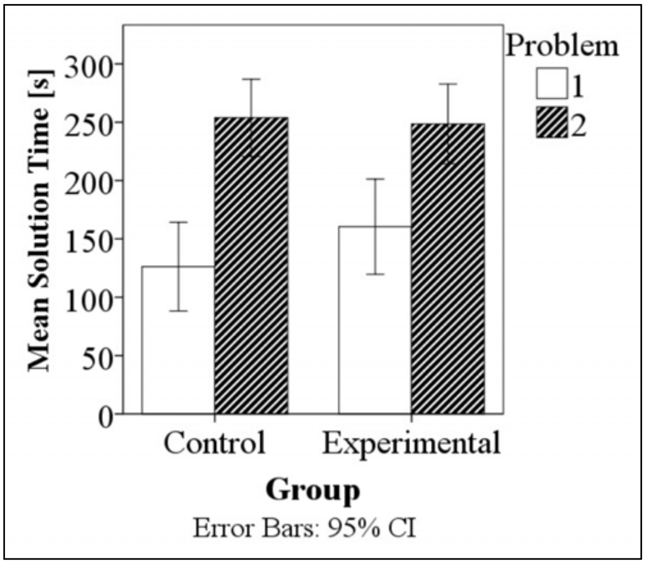

Fig. 2. Mean solution times across different problems and conditions

well (i.e., change + to =), and that the result may not only have the conventional form X = f(Y, Z) but also the form of the tautology X = X. The control problem did not require any representational change.

<u>*Inner speech suppression*</u>

The restriction of inner speech was induced by an irrelevant speech effect: Participants in the experimental group listened to a monotonously spoken, repetitive sequence of letters (A-G) while solving problems. There is empirical evidence that listening to irrelevant speech has similar consequences to overt repetition of irrelevant words (e.g. Ball *et al.* 2015; Ball & Stevens 2009; Marsh *et al.* 2021; Threadgold *et al.* 2019).

<u>*Investigation of the process of insight problem solving*</u>

The process of insight problem solving was examined by analysis of the participants' eye movements. Eye movements were recorded by an GazePoint High Definition EyeTracker eye-tracker with a sampling frequency of 150 Hz. To evaluate different characteristics of the solution process, the total solution time for each participant was divided into 3 equally long intervals, which are further referred to as: Interval 1, Interval 2, Interval 3. The mean fixation length was calculated from all fixations longer than 100 ms.

It is the long fixations that should be associated with deeper processing of given object (Knoblich *et al.* 2001). Fixations was considered as "long" when their length exceeded the median value for a given participant. The proportions of long fixations allocated to a particular element were calculated according to the formula: Total time of long fixations of given element/total time of long fixations of all elements.

According to Knoblich *et al.* (2001) the following patterns of eye movements are characteristic for different aspects of the solution process: (A) *The initial maladaptive representation of the problem:* For all problems, participants allocate a higher proportion of long fixations to values (results and operands) than to signs (operators 1 and 2) during Interval 1. (B) *The impasse stage:* For problems requiring representational change, the average length of fixations made during the total solution time is higher than for problems that do not require it. Also, for problems requiring representational change, the average length of fixations increases monotonously with each further interval. (C) *The representational change:* Successful participants allocate a greater proportion of long fixations to the crucial element of the problem (the result in problem1 and the operators in problem 2), in Interval 3 in comparison to Interval 1, but unsuccessful participants do not.

To investigate how inner speech restriction affects the solution process, we derived a way to compare its above-mentioned aspects between subjects in control and experimental group. Following eye movements patterns were compared between groups: (A) *The initial maladaptive representation of the problem:* Proportions of long fixations allocated to problem elements during Interval 1. Greater proportion of long fixations allocated to values is an indicator of a greater fixation on the conventional representation of the problem. (B) *The impasse stage:* Average length of fixations during intervals and total solution time of both problems. Higher average length of fixations is an indicator of a longer time spent by experiencing impasse. (C) *The representational change:* Proportions of long fixations allocated to the crucial elements of problem 1 (result) and problem 2 (operators) during Interval 3. Lower proportion of long fixations allocated to crucial elements of problems is an indicator of higher difficulty of reaching the representational change.

<u>*Procedure*</u>

Participants were tested individually in the presence of the researcher, in a quiet and well-lit room. Each participant first underwent a simple Roman numeral recognition task. Participants were then familiarized with the rules of solving matchstick arithmetic problems and were given 5 min to solve the control problem. All participants in our study succeeded in solving the control task. Participants were then instructed not to move their head and to look only at the screen. Their head position was fixated using chin rest. Before the experiment, participants underwent a calibration procedure for the eye-tracker. Participants in the experimental group were then given supra-aural headphones and continued the experiment while listening to a recording of irrelevant speech. Participants in the control group continued the experiment under standard conditions. All participants were presented with problems 1 and 2 in a random order on a screen with resolution 1920×1080 in Ogama software. Participants were instructed to first raise their hand and then write

Tab. 1. Eye movements of participants in the control/experimental group during problems solving

			Problem 1						Problem 2					
			Control Group			Experimental Group			Control Group			Experimental Group		
			N	M	SD	N	M	SD	N	M	SD	N	M	SD
Percentage of long fixations in the Int.1*	Result		29	59	17.6	27	54.1	24.5	29	36.2	18.3	27	42.7	20.2
	Operator 1		29	6.4	9.6	27	9.57	17.9	29	9.8	9.4	27	7.55	5.9
	Operator 2		29	9.8	12	27	11.8	11.6	29	20.8	11.3	27	15.2	12.5
	Operands		29	24.8	18	27	24.6	14.6	29	33.2	12.4	27	34.6	18.2
Fixations length [ms]	Interval 1		29	298	65.8	27	315	117	29	299	67	27	304	91.4
	Interval 2		29	309	56.9	27	298	59.8	29	328	92.7	27	308	56.9
	Interval 3		29	316	59.8	27	328	127	29	316	72.4	27	337	171
Percentage of long fixations of the crucial element*	Int.1	SS**	23	63.5	16.9	22	56.7	23.9	9	27.6	14.7	8	17.3	13.8
		US**	6	41.9	5.8	5	42.5	26.3	20	31.9	12.4	19	25	15.1
	Int.2	SS**	23	49.8	31.1	22	51.2	25.2	9	25.2	31.7	8	29.6	20.2
		US**	6	36.1	12.9	5	40.1	21.9	20	33.5	12.4	19	25.4	17.3
	Int.3	SS**	23	70.4	22	22	52.6	24.2	9	34	28.6	8	26.6	13.1
		US**	6	25.8	14.7	5	39.1	25	20	31.5	15.4	19	24.3	12.6

Note: *Percentage of the amount of time allotted to long fixations of given element/all elements; **SS = successful solvers, US = unsuccessful solvers.

the correct version of the equation on a paper, when finding the solution. If the solution turned out to be incorrect, participants continued the task without pausing until the time limit expired.

Results

The data were analyzed in Jamovi 1.6.23. In the first section, we present results for performance variables (solution rates and times) relevant to testing both the representational change theory itself and the effect of the inner speech restriction on the solution performance. For eye movements, a large amount of data was obtained. In the second section, we therefore report separately results relevant only to the testing the representational change theory. In the third section, data concerning only the influence of the restriction of inner speech on the solution process are reported.

Solution rates and times

Differences in percentages of successful solvers were tested using Chi-square test of association. Problem 1 was solved by 79.3% of participants in the control group and 81.5% of participants in the experimental group, the difference was not statistically significant [X^2 (1, $N = 56$) = 0.04, $p = 0.84$, $V = 0.03$]. Problem 2 was solved by 31% of participants in the control group and 29.6% of participants in the experimental group, the difference was not statistically significant [X^2 (1, $N = 56$) = 0.01, $p = 0.91$, $V = 0.02$]. The difference in the percentage of successful solvers of problem 1 vs. problem 2 in the control group was also not statistically significant, [X^2 (1, $N = 29$) = 0.73, $p = 0.39$, $V = 0.16$].

Differences in solution times were tested using a 2 × 2 ANOVA, with the problem as a within-subjects factor (problem 1, problem 2) and the inner speech restriction as a between-subjects factor (control, experimental group). Problem 1 was solved within a shorter time than Problem 2 [$F(1, 54) = 41.89$, $p < 0.001$, $\eta^2 = 0.25$]. However, there was no statistically significant difference between the solution times in control and experimental groups, [$F(1, 54) = 0.59$, $p = 0.45$, $\eta^2 = 0.005$], nor was statistically significant an interaction of these factors [$F(1, 54) = 1.41$, $p = 0.24$, $\eta^2 = 0.008$]. The results are shown in Figure 2.

Eye movements: Testing the representational change theory

Descriptive statistics for the eye movements of participants is provided in Table 1. Differences in the proportions of long fixations allocated to elements of problems during Interval 1 were tested using 2 x 4 ANOVA with problem (problem 1, problem 2) and element (result, operator 1, operator 2, operands) as within-subject factors. Problem type was not a statistically significant factor [$F(1, 28) = 0.36$, $p = 0.56$, $\eta^2 < 0.001$]. However, statistically significant differences were found for elements [$F(3, 84) = 62.89$, $p < 0.001$, $\eta^2 = 0.49$], and the interaction of the factors problem type x element was also statistically significant [$F(3, 84) = 14.23$, $p < 0.001$, $\eta^2 = 0.1$]. Post-hoc tests with Bonferroni correction were conducted to verify that the differences found were consistent with the pattern expected by the representational change theory. Overall, participants allocated higher proportion of long fixations to the result than to the operands [$t(28) = 4.80$, $p < 0.001$], to the operands than to the operator 1 [$t(28) = 7.24$, $p < 0.001$] and the operator 2 [$t(28) = 4.51$, $p < 0.001$].

Differences between mean fixations lengths during intervals of problems 1 and 2 were tested using 2 × 3 ANOVA with problem (problem 1, problem 2) and interval (1, 2, 3) as within-subject factors. We found no statistically significant differences between problem types [$F(1, 28) = 0.30$, $p = 0.59$, $\eta^2 = 0.002$], intervals [$F(2, 56) = 2.31$, $p = 0.11$, $\eta^2 = 0.02$], and statistically significant was neither the interaction of these factors [$F(2, 56) = 0.60$, $p = 0.56$, $\eta^2 = 0.004$].

Differences in the proportions of long fixations of the crucial elements of problem 1 (result) and problem 2 (operators) between intervals and successful vs unsuccessful participants were tested using a 3 × 2 ANOVA for both problems. Interval (1, 2, 3) was the within-subjects factor and solution success (yes, no) was the between-subjects factor. For problem 1, there was no statistically significant difference between the intervals [$F(2, 54) = 0.97$, $p = 0.39$, $\eta^2 = 0.02$]. The interaction of the factors interval x success was also not statistically significant [$F(2, 54) = 2.66$, $p = 0.079$, $\eta^2 = 0.05$]. However, successful participants allocated a statistically significant greater proportion of long fixations to the result than did unsuccessful participants [$F(1, 27) = 17.8$, $p < 0.01$, $\eta^2 = 0.19$]. For problem 2, there were no statistically significant differences between intervals [$F(2, 54) = 0.32$, $p = 0.73$, $\eta^2 = 0.006$], successful vs. unsuccessful participants [$F(1, 27) = 0.46$, $p = 0.50$, $\eta^2 = 0.008$]. The interaction of these factors was also not statistically significant [$F(2, 54) = 0.70$, $p = 0.50$, $\eta^2 = 0.01$].

<u>*Eye movements: Testing the influence of the inner speech suppression*</u>

Differences between the control and experimental group in the proportions of long fixations allocated to problem elements during Interval 1 were tested by One-way ANOVA for both problems. For problem 1, there were no statistically significant differences in the proportions of long fixations allocated to result [$F(1, 54) = 0.76$, $p = 0.39$], operator 1 [$F(1, 54) = 0.70$, $p = 0.41$], operator 2 [$F(1, 54) = 0.40$, $p = 0.53$], or operands [$F(1, 54) = 0.003$, $p = 0.96$]. For problem 2, there were no statistically significant differences in the proportions of long fixations allocated to result [$F(1, 54) = 1.59$, $p = 0.21$], operator 1 [$F(1, 54) = 1.12$, $p = 0.29$], operator 2 [$F(1, 54) = 3.13$, $p = 0.08$], or operands [$F(1, 54) = 0.12$, $p = 0.74$].

Differences between the control and experimental group in the length of fixations during each interval, as well as total solution time, were tested using One-way ANOVA for both problems. For problem 1, there were no statistically significant differences in the length of fixations during Interval 1 [$F(1, 54) = 0.42$, $p = 0.52$], Interval 2 [$F(1, 54) = 0.49$, $p = 0.49$], Interval 3 [$F(1, 54) = 0.73$, $p = 0.40$], or total solution time [$F(1, 54) = 0.19$, $p = 0.66$].

For problem 2, there were no statistically significant differences in the length of fixations during Interval 1 [$F(1, 54) = 0.06$, $p = 0.80$], Interval 2 [$F(1, 54) = 1$, $p = 0.32$], Interval 3 [$F(1, 54) = 0.34$, $p = 0.56$], or total solution time [$F(1, 54) = 0.13$, $p = 0.72$].

Differences between control and experimental group in the proportions of long fixations allocated to the crucial elements of the problems during Interval 3 were tested using independent t-test. There were no statistically significant group differences in the proportions of long fixations allocated to the result of problem 1 [$t(54) = 1.58$, $p = 0.12$, $d = 0.42$], and operators of problem 2 [$t(54) = 0.84$, $p = 0.41$, $d = 0.22$].

Discussion

<u>*Solution rates and times*</u>

Considering performance variables, we firstly investigated whether solution rates and times for matchstick arithmetic problems are consistent with the representational change theory, according to which, the successful solution of the problem depends on the change of its initial representation (Knoblich *et al.* 1999). Since problem 2 places higher demands on the representational change than problem 1, it should be solved less frequently and after longer time. The difference in the proportions of successful participants was in the expected direction, but not statistically significant. However, solution time is presumably a more sensitive indicator of the problem difficulty and we found that problem 2 took significantly longer time to solve than problem 1. Thus, it seems that tasks used really measured the ability of restructuration.

Next, one of our goals was to investigate whether inner speech restriction impairs the ability of solving these problems. Drawing on the Fernyhough's (1996, 2009) dialogical thinking framework, according to which creative problem solving may depends on the dialogical interactions mediated by inner speech, we assumed it does. The findings of Ball and Stevens (2009) were further considered as an empirical support for this assumption, though the authors interpreted them in a different way. The results did not support our expectations - there were no statistically significant differences between the control and experimental groups in the proportions of successful solvers or solution times for any of the problems. Several explanations seem plausible.

Firstly, although matchstick arithmetic problems are similarly to CRAT presented in symbolic form (numbers and operands), manipulation with matchsticks in analogical form (e.g., mental rotation) may still be an important aspect of the solution process. In this way, they would be more like visuo-spatial problems, for solution of which, the inner speech may be unnecessary or even detrimental (Ball *et al.* 2015). Also, regardless of the role of visuo-spatial manipulation of the elements in matchstick arithmetic solving, their mathematical nature may be crucial - inner speech could be important for finding unconventional ideas only in specific domains.

Alternatively, inner speech might be not involved in finding solutions through the inner dialogue. Threadgold *et al.* (2019) suggested that it is important rather for testing possible solutions in CRAT, where a series of 3 words need to be sequentially replayed in the mind - hence, other insight problems may require testing solutions through different mechanisms.

Finally, the effect of the inner speech restriction on insight problem solving might be not more specific but rather weaker than we expected. The length of the time limit could then be of importance - if participants have a long time limit for a solution of single problem, they might be able to compensate inner speech restriction to the extent that it is not affecting the performance anymore. This suggestion is driven by the fact that the length of the time limit is one of the differences between our experiment and the study by Ball and Stevens (2009), in which participants had max 30s to solve a single CRAT.

Eye movements: Testing the representational change theory

The eye movements patterns, which should be associated with different aspects of the solution process were firstly analyzed for participants in the control group in order to test, whether they are consistent with the representational change theory (Knoblich *et al.* 2001).

The first prediction concerned the distribution of attention (proportions of long fixations) among the problem elements during Interval 1. Participants should pay more attention to the values than to the operators because they are relying on experience of solving traditional equations, where values are thought of as variables and operators as constants (Knoblich *et al.* 2001). The results were consistent with the theory.

The second prediction concerned the impasse stage. Impasse should be manifested by making fewer fixations (and within a time limit, by higher average fixation length) due to the exhaustion of the possible moves offered by the inappropriate initial representation (Knoblich *et al.* 2001). Its presence should be observable in two ways (see Methods). We tested only the second assumption, according to which the length of fixations should monotonously increase with each further interval. No significant differences were found between intervals of neither problem. The absence of the expected results may be caused by limitations of our study, however, it is also worth consideration that this second way of evaluating the presence of the impasse may not be reliable. It assumes that participants go through a fixed sequence of stages from searching the wrong problem space through the impasse to the representational change and solution finding. But if the solution is a result of a series of multiple representational changes, each preceded by an impasse of varying length, the largest proportion of time spent by impasse may take place in other than the last interval. Fedor *et al.* (2015) indeed found that for the five-square problem, most participants go through a more complex sequence of stages, involving repeated transitions from searching the problem space to the impasse, insight and back. This does not necessarily imply that the impasse cannot be identified by increasing fixation length. It may be argued that even though individual participants usually do not go through the strict sequence of stages, the method is still applicable on the group level analysis, or that some problems are more likely to invoke a single impasse stage. However, it could be worthwhile to further investigate this area in more detail.

The last prediction concerned changes in the distribution of attention - only successful participants should pay more attention to the crucial problem element in Interval 3 in comparison to Interval 1. For problem 1, successful participants paid more overall attention to the result than unsuccessful participants, but without the expected change between intervals (an interaction of the factors success x interval) that would have indicated a representational change. No differences were found for problem 2. In this case, the results are inconsistent not only with the original study by Knoblich *et al.* (2001) but also with the work of Tseng *et al.* (2014), who replicated their findings for problem 2.

Eye movements: Testing the influence of the inner speech suppression

The influence of the inner speech restriction on the process of insight problem solving was investigated by comparing the specific eye movement patterns of participants in the control and the experimental group. The results indicate that it did not affect the initial problem representation, the impasse, nor the shift in the representation. It should be noted however, that the impasse and the representational change as such were not captured by their supposed eye movements patterns in the control group. Therefore, in these 2 cases it is not possible to tell if the results truly reflect an absence of the effect of inner speech suppression.

Nonetheless, even these findings are consistent with those obtained for performance measures.

Limitations

Our findings are limited by the size of the research sample. We could compare only 23 vs. 6 subjects when we were testing differences in the proportions of long fixations allocated to the crucial element of problem 1 between successful and unsuccessful participants in control group. However, other studies worked with similar sample sizes: Knoblich *et al.* (2001) compared 18 vs. 6 participants for the easier problem, Tseng *et al.* (2014) 12 vs. 24 for the harder one. Future research could therefore prioritize investigating eye movement patterns on a larger sample. However, this is problematic due to time constraints and difference between the sizes of successful and unsuccessful solver groups. Another limitation concerns the applied method of inner speech restriction. The secondary verbal task in the experimental group should be ideally complemented by a similarly demanding visuospatial task in the control group (Nedergaard *et al.* 2023). We chose a simpler design, due to the need of accurate capture of eye movements. Therefore, it is not possible to reliably separate the effect of the inner speech restriction from the mere increase in the cognitive load level. Future research could complement the study with an experiment comparing the effects of verbal and visuospatial secondary tasks.

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