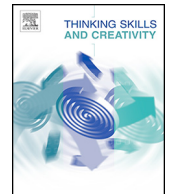




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## Verification of Dual Factors theory with eye movements during a matchstick arithmetic insight problem



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### ABSTRACT

Representational Change Theory claims that participants form inappropriate representations at the beginning of the insight problem solving process and that these initial representations must be transformed to discover the solution (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001; Ohlsson, 1992). The theory also claims that all participants are trapped by inappropriate representations, regardless of the result, but it is easier for successful participants to transform their initial representations. However, the transformation of representations is not the only critical factor. This study investigates the hypothesis that the process of fixedness averting plays an important role in insight problem solving and is helpful for representational change. To verify the influence of fixedness averting on representational change processes, matchstick arithmetic problems were employed as an experimental model. In experiment 1, insight problem solving results could be predicted within the first third of the duration of the task. The gaze duration in the fixation region of successful participants was shorter than the gaze duration of unsuccessful participants. In experiment 2, participants' foci of attention were experimentally manipulated by presenting different animated diagrams to guide their attention. We found that the rate of correct responses was significantly reduced when participants' attention was guided to the fixation region. Representational Change Theory declares that changing inappropriate initial representations is necessary for solving insight problems. The present study demonstrates that in addition to representational change, fixedness averting is also crucial to problem solving.

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## 1. Introduction

In the initial stage of an insight problem-solving process, participants usually encounter an impasse and remain perplexed regarding the problem, despite having numerous thoughts about the problem. A sudden moment of inspiration (i.e., the "aha!" moment) occurs, and the puzzle of the insight problem disappears. The inner processes of insight problem solving

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require further empirical explanation. Generally, insight problem solving theory agrees that the characteristic features of insight problems are “open questions and closed answers” (Wakefield, 1992). The nature of the question itself is wide open, which causes participants to form an inappropriate initial presentation of the question. In contrast, the answer to the question is characterized as closed (i.e., there is always exactly one answer, which is associated with knowledge that is less familiar to the solver). Furthermore, the insight problem solving process is also characterized by discontinuity, which is contrary to the step-by-step sequence strategy in general question solving (Weisberg, 1995). The initial representations formed by participants are usually invalid and must be restructured before participants can discover the solution (Duncker, 1945; Mayer, 1995). Restructuring has been claimed as the only manner in which insight problems can be solved (Chein & Weisberg, 2014; Weisberg, 1995).

### 1.1. Representational Change Theory

Ohlsson (1992) proposed Representational Change Theory, and this theory has proven to be effective for interpreting the inner processes of insight problem solving in many studies following its publication (Jones, 2003; Kershaw & Ohlsson, 2004; Knoblich, Ohlsson, Haider, & Rhenius, 1999; Knoblich, Ohlsson, & Raney, 2001; Öllinger, Jones, & Knoblich, 2006; Öllinger, Jones, & Knoblich, 2013). Because the impasses are derived from inappropriate problem representations, which are based on individual experiences, Representational Change Theory claims that the restructuring of inappropriate representations is necessary to break the impasse. Previous studies have employed measures of response time and success rate to investigate insight problem solving (MacGregor, Ormerod, & Chronicle, 2001; Öllinger et al., 2006; Weisberg & Alba, 1981; Weisberg & Suls, 1973). However, some information regarding the thinking process cannot be observed with these two measures. Some researchers have used interviews or protocols that involve thinking aloud (Kaplan & Simon, 1990); however, the former is affected by biases in individual memory, and the latter evokes real-time interference upon the problem solving process. The inner cognitive processes remain unidentified by participants using these two techniques. Considering the results of previous approaches, we suggest that eye movement monitoring is more suitable for observing the insight problem solving process because this method involves real-time eye movement tracking and recording, which is free of interference from the thinking processes that occur during insight problem solving. The eye-tracking technique is being increasingly employed among studies in relevant research fields.

Knoblich et al. (2001) utilized eye movement tracking techniques to examine Representational Change Theory. In his study, he used matchstick arithmetic problems as an experimental task model in which an arithmetic statement was expressed illogically in Roman numerals and depicted by matchsticks. The participants' objective was to make the statements reasonable by moving only one matchstick. For example, if the statement was “III = III + III,” the correct solution involved turning the plus sign into an equal sign. Relocating only the vertical matchstick of the plus sign into a horizontal position made the statement reasonable, i.e., “III = III = III”. Regarding the interpretation of this problem-solving dilemma, the researchers claimed that participants would initially see the statement based on a stereotype of arithmetical equations, which would lead individuals to assume that only numerals were changeable whereas operands were not. Hence, the inappropriate representation was formed under the assumption that the matchsticks composing numerals were movable, while the matchsticks of the operands were not. According to previous research (Knoblich et al., 2001), dwell times on the numeral elements were significantly longer than dwell times on the operand elements during the first third of the problem solving process. This finding supports the assumption of Representational Change Theory in that the initial inappropriate representations mislead participants into a deadlock.

In addition to the improper constraint that was placed on the insight problem solving solution (i.e., numerals were variable elements and the operands were constants), the participants derived another restriction that assumed that only one equal sign should exist in the equation (Knoblich et al., 2001). Therefore, participants attempted to equalize the values on either side of the equal sign by moving the matchsticks of the numerals. Without exception, the statement remained unreasonable by this method. For example, moving one of the numeral matchsticks from the right side to the left side of the equal sign (“IIII = II + III”) results in an unreasonable equation. As a next step, the participants might move the first and second matches of the “III” on the left side to create the arithmetic statement “VI = III + III.” This solution also fails the task because it requires the movement of two matches to form the symbol “VI.” These suppositions about the problem solving process were supported by the results of a study (Knoblich et al., 2001) which found that a greater percentage of dwell time was spent on the numeral elements compared with the operand elements in the initial period of problem solving. Specifically, gazing time at the numeral elements of the left side was significantly greater than the gazing time on the right side.

Representational Change Theory claims that the transformation of invalid representations is necessary for breakthroughs in problem solving. There are many ways of transforming representations; Knoblich et al. (2001) believed that constraint relaxation was one way of doing so. Constraint relaxation provided a good interpretation of how an insight problem could be difficult but also solvable (Ohlsson, 1992). For example, to solve the radiation problem, participants merely need to free themselves from the constraint that only one laser beam can be fired (Duncker, 1945). As another example, in the nine-dot puzzle, participants are required to draw a line that escapes from the border of a square (Weisberg & Alba, 1981). As for the matchstick arithmetic problem, participants are not able to find the answer if they fail to accept the idea that the matchsticks of the operand elements are moveable. In agreement with our hypotheses, the results of relevant studies

examining this problem have shown that the percentage of dwell time on the operand elements grows longer over the course of the experiment in successful participants but remains unchanged in unsuccessful participants.

### 1.2. Fixedness averting as an important factor in insight problem solving

Representational change has been proposed to be the only effective factor in solving insight problems (Knoblich et al., 2001). However, the present study claims that role of fixedness averting should be defined and discussed in terms of the insight problem solving process. Rather than a simultaneous occurrence, sequential relationships are assumed to exist between fixedness averting and activating key knowledge. Therefore, the present study proposes that successful participants will know to avoid invalid logic in insight problem solving, which is consequently helpful in representational change. The results of previous related research studies have also indicated that fixedness averting is a critical stage in the creative design process (Agogué, Poirel, Pineau, Houdé, & Cassotti, 2014; Chrysikou & Weisberg, 2005).

Studies of incubation have claimed that the deactivation of invalid logic is helpful for finding true answers. Incubation implies that correct rates can be increased by temporarily putting the task away and ignoring the impasses (Wallas, 1926). During this “off time,” individuals can transfer their focus to anything but the original task, to set aside invalid logic and downgrade the activation of their initial problem solving strategies. As a result, incubation helps participants to think effectively when they return to the task. Moreover, intense examination of the relationship between working memory, cognitive ability, and insight problem solving has revealed that performance in insight problem solving is positively related to creative performance in flexibility tests, which include figural fluency and alternative uses of daily things (Gilhooly & Murphy, 2005). Flexibility refers to individuals’ tendencies to use potential problem solving strategies rather than grasping onto the only obvious solution.

Furthermore, Mednick (1962) association theory of creative process interprets the inner cognitive processes of creative individuals. This idea provides a potential explanation of the inner cognitive process during insight problem solving. This theory claims that most individuals respond more intensely to typical stimuli. However, this is not the case in creative people. The intensities of responses to various stimuli are not significantly different in creative people. In particular, creative people respond weakly to typical stimuli but strongly to non-typical stimuli; this response behavior indicates that creative people do not grasp onto initial inappropriate solutions but, rather, integrate exceptional concepts into solutions. The results of relevant studies have shown that performance on Mednick’s Remote Associates Test (RAT; Mednick & Mednick, 1967) was positively correlated with performance on insight problems (e.g., Akbari Chermahini, Hickendorff, & Hommel, 2012; Huang, Chen, & Liu, 2012). Some research studies have directly used Mednick’s RAT as material on insight problem tasks (Bowden & Jung-Beeman, 2003; Chein & Weisberg, 2014; Sandkühler & Bhattacharya, 2008).

In previous studies, fixedness has also been attributed as a barrier to insight problem solving. The results of studies employing candle and two-string problems have shown that participants who address the problem of functional fixedness focus their attention on the common functions of objects but rarely think of alternative functions that are helpful in insight problem solving (Duncker, 1945; Maier, 1931). Solving the candle problem requires participants to associate the alternative function of a box as a platform rather than a container. Answering the two-string problem requires participants to use a brush as a pendulum rather than merely a brush. These studies have highlighted the impasses of insight problem solving that are caused by fixedness; however, it requires further clarification of the relationship between fixedness and the changing of inappropriate representations. Additionally, ‘mental set’ refers to the notion that individuals maintain invalid problem solving strategies (i.e., the strategies chosen by individuals are based on successful solutions to similar problems that occurred earlier, Luchins, 1942). Previous studies have sought to elucidate the influence of mental set on insight problem solving and have analyzed participants’ performance on insight problem solving tasks and non-insight problem solving tasks (Öllinger, Jones, & Knoblich, 2008). The results of these studies show that participants’ performances were restricted if the appropriate strategies of representation transformation for the two sequential tasks were different. For example, if a participant used a chunk decomposition strategy on an earlier task and a strategy of releasing restrictions on a later task, that participant’s performance was inhibited. Invalid problem solving strategies constrain the retrieval of effective solutions.

Fixedness averting is a potentially important factor in insight problem solving; however, this factor has not been verified in previous studies. One study employed the radiation problem as the task material and indicated that the tumor region was not relevant to the problem solving task by comparing the percentage of time spent gazing at the tumor region between the successful and unsuccessful groups. This study found that, 30 s after the beginning of the task, the gazing time spent on the tumor region by the unsuccessful group was more than the gazing time of the successful group (Grant & Spivey, 2003). However, this difference was not significant, likely due to the low statistical power of the study caused by the low number of participants (14 total participants, 5 in the successful group and 9 in the unsuccessful group). Thus, the influence of fixedness requires further verification. Successful and unsuccessful participants could not be discriminated during the initial period of problem solving in another previous study (Knoblich et al., 2001).

### 1.3. Dual Factors theory vs. Representational Change Theory

According to Representational Change Theory, all individuals fall into fixedness with no differences in intensity during the initial period of the problem solving task, and the only path to problem solving involves changing their representation. Representational Change Theory has narrowly focused on the effect of transforming representation. The claim of

**Table 1**

The hypotheses of the Representational Change Theory and the Dual Factors theory regarding the dwell time percentages of the successful and unsuccessful groups at different regions in each period of matchstick arithmetic problem solving.

Theory	Problem solving period	Dwell time at fixation region (III on the left side of equal mark)	Dwell time at key region (plus mark)	Dwell time at rest regions (equal mark, III on the right side of equal mark, III on the right side of plus mark)
Representational Change Theory	First 1/3 period	<b>SG = UG</b>	SG = UG	SG = UG
	Middle 1/3 period.	SG < UG	SG > UG	SG = UG
	Last 1/3 period	SG < UG	SG ≫ UG	SG = UG
Dual Factors theory	First 1/3 period	<b>SG &lt; UG</b>	SG = UG	SG = UG
	Middle 1/3 period.	SG < UG	SG > UG	SG = UG
	Last 1/3 period	SG ≫ UG	SG ≫ UG	SG = UG

Note: SG, successful group; UG, unsuccessful group. << (>>), a significant difference, "< (>)" a difference.

single-attribution highlights the need to verify the potential influence of fixedness in insight problem solving. To address this issue, the present study proposes a Dual Factors theory of the insight problem solving process; these dual factors are fixedness averting and representational change. Dual Factors theory also argues that fixedness averting is critical to representational change. Individuals who avert fixedness will change representations smoothly in subsequent periods of problem solving and then arrive at the solution. However, those who are unable to free themselves from fixedness are not able to proceed with representational change.

To verify our Dual Factors theory, the present study recruited sufficient participants, used the matchstick arithmetic problem as the experimental task, and analyzed the eye movement records of the participants during the problem solving task. We hypothesized that the percentage of time spent dwelling on the regions of the arithmetic equation would reflect individuals' inner representations of the task. The entire equation "III = III + III" was viewed as a diagram that was divided into five regions. From the left to right side, the statement included following regions: the Roman numeral III on the left side of the equal sign; the equal sign region; the region of the Roman numeral III on the right side of the equal sign; the plus sign region; and the region of the Roman numeral III on the right side of the plus sign. Generally, participants were trapped by the invalid strategy of repositioning the Roman numeral III into a Roman numeral IV within the region of the Roman numeral III on the left side of the equal sign; this region was defined as the "fixation region" in the present study. The region of the plus sign was defined as the "key region" because the participants shifted their attention to other regions when they were free from the following two thoughts: "operand elements are unmovable" and "only one equal sign exists in a reasonable equation." The hypotheses of present study were as follows:

- (1) Dual Factors theory assumes that the degree of fixedness in the successful group will be less than the degree of fixedness in the unsuccessful group. Thus, the percentage of time that the successful group spends dwelling on the fixation region will be significantly less than the percentage of time spent by the other group during the first third of the of task. Representational Change Theory assumes that the degree of fixedness will be the same in both groups; therefore, the dwell time percentages of both groups will be equal during this period of task.
- (2) Dual Factors theory and Representational Change Theory both assume that representational change is necessary for insight problem solving. Representational change will occur only in the successful group and fixedness will prevail in the unsuccessful group. Consequently, the dwell time percentages in the key region will be significantly greater in the successful group than in the unsuccessful group, and the dwell time percentage on the fixation region in the unsuccessful group will be significantly greater than in the successful group during the middle third of the problem solving process.
- (3) During the final third of the problem solving task, the most successful participants will have carried out representational change. Therefore, in the successful group, the dwell time percentage on the key region will be significantly greater than in the unsuccessful group, and the dwell time percentage on the fixation region in the unsuccessful group will be significantly greater than in the successful group.

**Table 1** presents a summary of the hypotheses of present study and the differences between the two theories are presented in bold type.

#### 1.4. Verification of the causality of fixedness averting and representational change

In present study, experiment 1 had a quasi-experimental design and sought to confirm the correlation between fixedness averting and representational change. To determine the causal relationship between fixedness averting and representational change, a second experiment was conducted to verify the direct influence of fixedness on representational change. A previous study (Grant & Spivey, 2003) analyzed the eye movement records of participants solving the radiation problem and found that the dwell time percentage on the skin region in the successful group was greater than in the unsuccessful group. Furthermore, this study demonstrated that treatment of the animated skin diagrams significantly increased the success rate. Guiding individuals' perception with animated diagrams influences the process of insight problem solving.

To address the effect of fixedness on representational change, the second experiment of the present study followed the idea of guiding perception. The present study assumed that hinting at the fixation region would enforce fixedness and therefore decrease success rates, while hinting at the key region would aid in eliminating fixedness and thereby increasing the success rate. In experimental group 1, the treatment was shown in the form of an animated fixation region diagram designed to enforce participants' fixedness. The animated fixation region steadily drew the individuals' attention to that region and caused them to fixate on the invalid solution (i.e., reposition the numeral III to create a numeral IV). In experimental group 2, the treatment was shown in the form of an animated key region diagram designed to diminish fixedness. This animation provided a clue that the operand marks were movable. However, the participants were still constrained by the presupposition that only one equal sign was reasonable in the equation. Thus, the participants would still pick up the vertical matchstick of the plus sign while wondering where to place it.

## 2. Experiment 1

Representational Change Theory claims that individuals initially form inappropriate impressions of an insight problem, regardless of whether they ultimately solve the problem. Participants arrive at the solution via successful transformation of the inappropriate impression. Furthermore, the present study assumed that, prior to representational change, the successful individuals would not deeply process the invalid representation and would, therefore, be able to move beyond that invalid representation and achieve representational change.

To examine this assumption, the eye movement records of the participants solving the insight problems were analyzed to examine the differences in the dwell time percentage between the successful and unsuccessful groups during the three periods of the problem solving process.

### 2.1. Method

#### 2.1.1. Participants

Forty-one college and graduate students with an average age of 22 years were recruited. The participants had normal vision or corrected-to-normal vision. After screening out 3 participants who were likely to know the solution to the matchstick arithmetic problem, the valid sample included 38 participants.

#### 2.1.2. Experimental design

The design of this experiment was quasi-experimental. The independent variables were as follows: "result of problem solving," "regions", and "periods of the problem solving process." The result of problem solving was a between-subjects variable design that included two groups, the successful and unsuccessful groups. The region and periods of the problem solving process were the within-subjects variables. Regarding region, the matchstick arithmetic equation was divided into the following five regions, as illustrated in Fig. 1: the fixation region, the equal sign region, the key region, the equal sign region, the III on the right side of the plus sign.

Regarding the periods of problem solving process, the duration of the task was individually divided into three equal and sequential periods to observe the dynamics and continuity of the problem solving process. Thus, the first third, middle third, and final third periods were defined; this division is consistent with a previous study (Knoblich et al., 2001). The percentage of dwell time within each region was considered the dependent variable.

#### 2.1.3. Equipment

The equipment included a Dell Optiplex Gx620 desktop computer, an EyeLink 1000 with a chin and forehead rest (head supported), and a Chimei 19PS monitor for presenting the material. In the EyeLink 1000, the eye-tracking mode was set as pupil to cornea tracking, and the sample rate was set at 1000 HZ. The spatial resolution was 0.01°. The gaze bias tolerance

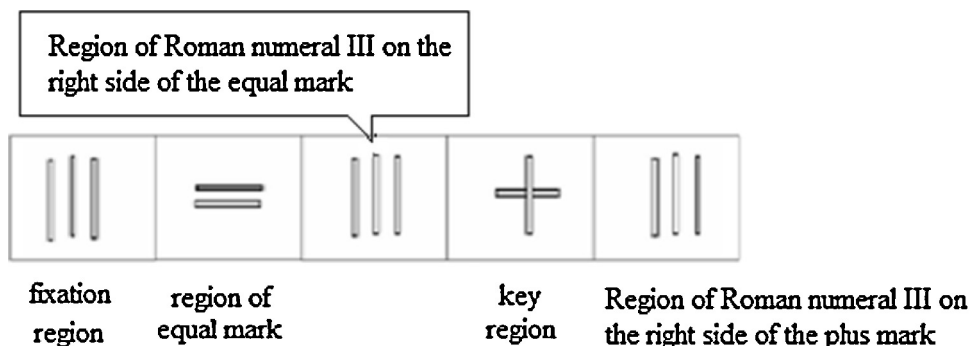


Fig. 1. Diagram of the five regions of the matchstick arithmetic equation.

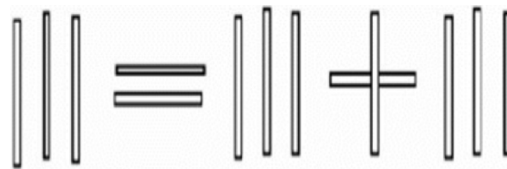


Fig. 2. Diagram of the matchstick arithmetic problem.

was set at  $0.15^\circ$ , which is more precise than the default setting ( $0.25^\circ$ – $0.5^\circ$ ). The mean end sample delay was less than 1.8 ms ( $M < 1.8$  ms). This eye tracking system was capable of real-time recording of fixations, saccades, and blinks, which are reflections of individual inner cognitive processes (Just & Carpenter, 1984; Rayner, 1995). The movements of the left eye were recorded, but the participants viewed the stimuli with both eyes during the problem solving process.

#### 2.1.4. Material

The experimental materials are shown in Fig. 2.

The participants were given the following instructions: “Here is an equation composed of several matchsticks. The numeric values are presented in the form of Roman numerals. This equation is not reasonable. Please make this equation logical by moving only one matchstick.”

The correct answer was to rotate the vertical matchstick of the plus sign 90 degrees into a horizontal position, making the equation: “III = III = III”.

#### 2.1.5. Procedure

- (1) Because Roman numerals are not commonly used in Taiwan, a test of Roman numeral recognition was administered to each participant prior to beginning the experiment to ensure that the participants were able to identify the numeric values. Every participant was required to identify the Arabic numerals that correspond to the following Roman numerals: (a) II; (b) IX; (c) VI; (d) VIII; and (e) XI.

If a participant responded incorrectly to any of these test numerals, information about Roman numerals was provided, and a retest was administered. The Roman numerals used in the retest were: (a) III; (b) V; (c) IV; (d) VII; and (e) XI. Participants advanced to the next step of the experiment only if they correctly responded to every item on the retest.

- (2) The following instructions for the experiment were presented on the screen:

*“This is a problem solving experiment. A calibration test is required to advance. Please look at the black point and do not move your head.”*

*“The calibration is completed, and this is the description of the question. Please ensure that you fully understand the question.”*

*“Here is the diagram of the question. Please solve it. When you have the answer, please tell us. If your answer is correct, the experiment will end. If your answer is not correct, please continue to work on the question. There is a 5-minute time limit. If you have SEEN this question before, please let us know NOW. Thank you.”*

- (3) If the participants had no questions about the experiment, then the participants were required to lean their foreheads against the stand of the eye tracker and place their jaws onto the jaw grip. The experimenter accordingly adjusted the focus of the camera. Then, a calibration test was conducted to calculate the corresponding pupil-to-cornea and visual material positions. Then, the participants were required to gaze at black points that were presented alone on the screen. These black points randomly appeared at different positions on the screen. A validation test was subsequently conducted to guarantee the accuracy of the calibration parameters. The procedure of the validation test was the same as the calibration test.
- (4) Next, the instructions were presented on the screen. If the participant had no questions, the experimental material was presented.
- (5) The matchstick arithmetic problem diagram was presented, and the eye movements of the participants were recorded. The participants could respond with their answer at any point. If the answer was correct, the experiment ended, otherwise the participant continued to work on the solution. The time limit was 5 min. The experiment ended at the time limit, even if the participant had not answered correctly.

## 2.2. Results

The mean, standard deviation, minimum and maximum problem solving time values (in seconds) are shown in Table 2. The mean problem solving time was 154.89 s in the successful group and 300 s in the unsuccessful group (i.e., the time limit).

The dwell time percentages for each of the regions were compared between the groups for each time period. The means and standard deviations are shown in Table 3.

**Table 2**

The mean, standard deviation, minimum and maximum problem solving time values (in seconds) of the successful and unsuccessful groups.

Groups	Mean	SD	Min.	Max.
Successful group ( $n = 12$ )	154.89	95.83	7.66	298.14
Unsuccessful group ( $n = 24$ )	300.00	0.00	300.00	300.00

**Table 3**

The means and standard deviations of the dwell time percentages for each regions between groups for each time period.

Periods	Groups	Fixation region		Equal mark		III on the right side of equal mark		Key region		III on the right side of plus mark	
		M (%)	SD	M (%)	SD	M (%)	SD	M (%)	SD	M (%)	SD
First 1/3 period	SG	18.05	8.71	10.24	3.96	23.20	7.23	20.34	10.08	16.36	9.35
	UG	24.51	12.91	10.69	4.82	20.32	8.22	20.67	10.92	16.16	6.62
Middle 1/3 period.	SG	16.73	11.06	12.33	9.57	22.78	10.74	27.27	16.66	19.53	13.61
	UG	25.67	10.79	9.50	4.20	20.30	9.43	18.62	8.81	16.99	9.27
Last 1/3 period	SG	11.62	9.17	13.04	8.23	22.11	8.23	31.42	13.53	18.79	13.33
	UG	22.14	12.09	9.91	5.54	21.29	11.94	19.01	10.17	17.76	10.18

Note. SG, successful group; UG, unsuccessful group.

### 2.2.1. The results of the *t*-tests on dwell time percentages by region and group for the first third of the time period

The dwell time percentages of the successful group on the fixation region were significantly less than those of the unsuccessful group in the first third time period (Fig. 3). The successful group spent 18.05% of their dwell time on the fixation region, and the unsuccessful group spent 24.51% of their dwell time in this region ( $t_{(36)} = -1.662, p < .05, d = .57$ ). There were no significant differences between the two groups in the other four regions.

### 2.2.2. The results of the *t*-tests on the dwell time percentages by region and group in the middle third of the time period

The dwell time percentages of the successful group at the fixation region in the middle third time period were significantly less than those of the unsuccessful group (Fig. 4). The successful group spent 16.73% of their dwell time in the fixation region, and the unsuccessful group spent 25.67% of their dwell time in this region ( $t_{(36)} = -2.44, p < .01, d = .82$ ). Moreover, the dwell time percentages of the successful group in the key region were significantly greater than those of the unsuccessful group. The successful group spent 27.27% of their dwell time in the key region, and the unsuccessful group spent 18.62% of their

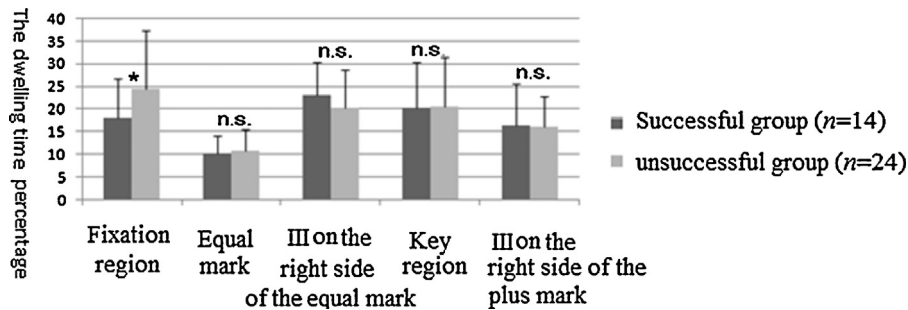


Fig. 3. The results of *t*-tests on dwell time percentages by region and group for the first third time period ( $*p < .05$ ).

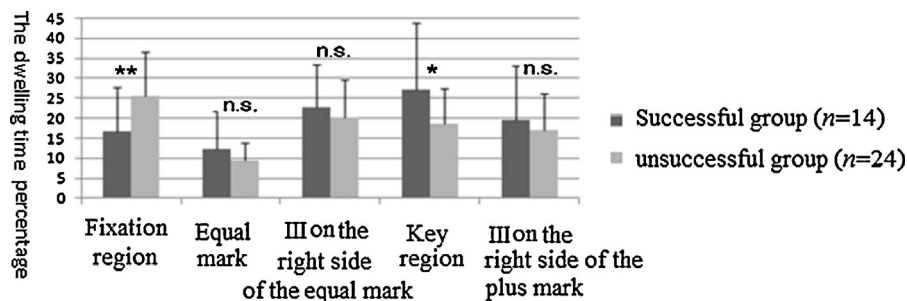


Fig. 4. The results of *t*-tests of the dwell time percentages by region and group in the middle third time period ( $*p < .05, **p < .01$ ).

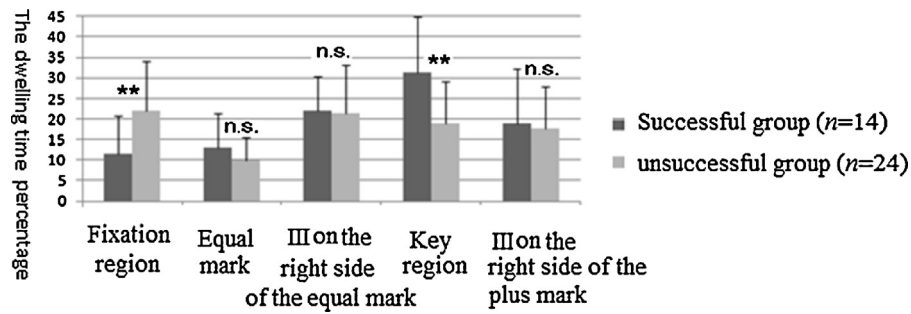


Fig. 5. The results of *t*-tests of the dwell time percentages by region and group during the last third time period (\*\* $p < .01$ ).

dwell time in this region ( $t_{(36)} = 2.10, p < .05, d = .65$ ). No significant differences in dwell time were found for the other three regions in the middle third time period.

### 2.2.3. The results of the *t*-tests on the dwell time percentages by region and group during the last third of the time period

The results were similar to those of the middle third time period. The dwell time percentages of the successful group in the fixation region were significantly reduced compared to the unsuccessful group during the last third time period (Fig. 5). The successful group spent 11.62% of their dwell time in the fixation region, and the unsuccessful group spent 22.14% of their dwell time in this region ( $t_{(36)} = -2.81, p < .01, d = .98$ ). However, the dwell time percentages in the key region of the successful group were significantly greater than those of the unsuccessful group. The successful group spent 31.42% of their dwell time in the key region, and the unsuccessful group spent 19.01% of their time in this region ( $t_{(36)} = 3.21, p < .01, d = 1.04$ ). No significant differences in dwell time were found for the other three regions during the last third time period ( $p > .05$ ).

### 2.3. Discussion

For experiment 1, the eye movement records were analyzed by time period. In general, our hypotheses were supported by the experimental results. As claimed by Representational Change Theory, the transformation of inappropriate representations was critical to insight problem solving; however, the fixedness averting that occurred during the first third of the time period was also critical to insight problem solving. The results of this experiment are summarized as follows:

- (1) The hypotheses were supported in the first third of the time period. The successful participants spent less time gazing at the fixation region compared with the unsuccessful participants. The differences in gazing times within the other regions were not significant between the two groups. These results show that the successful participants had not begun the process of representational change during this time period and were better at avoiding fixedness during the problem solving process. According to Representational Change Theory, all people create inappropriate representations in the early stages of problem solving, regardless of whether they eventually arrive at the correct solution. Moreover, based on the eye movement analyses, the present study proposes that the successful participants were better at avoiding the fixation region. A previous study (Grant & Spivey, 2003) that used the radiation problem reported that the percentage of time spent gazing at the tumor region in the unsuccessful group was non-significantly greater than in the successful group within the first 30 s of the task; the tumor region was not related to the correct answer in this task. However, the sample employed in Grant's study may have been too small to reach statistical significance. Therefore, we recruited a larger sample for this experiment (38 total participants, 14 in the successful group and 24 in the unsuccessful group). Consequently, the result of our *t*-test was significant.
- (2) In the middle third of the time period, the successful participants spent a significantly greater percentage of time in the key region, and the unsuccessful participants spent a greater percentage of time in the fixation region. Thus, our hypothesis was supported. This result revealed that the successful participants began to transform their representation during this time period whereas the unsuccessful participants continued to focus on the fixation region.
- (3) In the last third of the time period, the dwell time percentage of the successful group in the key region was significantly greater than in the unsuccessful group. Most of the successful participants were able to alter their representation, whereas the participants in the unsuccessful group were not able to alter their representation. Thus, our hypothesis was supported by this result.

### 3. Experiment 2

The results from the first experiment of the present study support the notion that fixedness and representational change are related. However, the causality of this relationship remained unclear. To address this issue, the effect of guiding attention was investigated in experiment 2. Animated diagrams were used to provide hints, as indicated by a previous study that employed this technique (Grant & Spivey, 2003). The materials of experiment 2 were animated diagrams of the matchstick



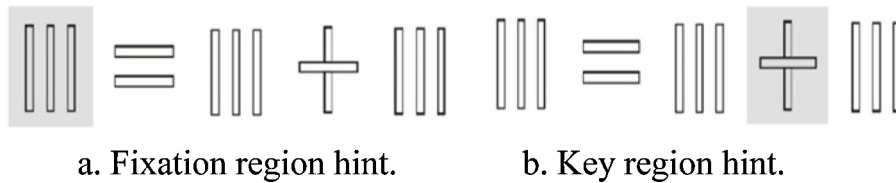


Fig. 6. Diagram showing fixation region and key region hints.

Table 4

The means, SDs, and ranges of the problem solving times (in seconds) for each group.

Group	Mean	SD	Minimum	Maximum
Fixation region hint group ( $n=31$ )	268.21	75.22	31.23	300.00
Key region hint group ( $n=32$ )	201.06	113.53	19.96	300.00
Control group ( $n=31$ )	231.05	104.92	21.86	300.00

arithmetic problem. The participants were randomly assigned into one of three groups: a fixation region hint group, a key region hint group, and a control group (i.e., a static diagram condition). The dependent variable was the success rate.

### 3.1. Method

#### 3.1.1. Participants

The sample was composed of 98 undergraduate and graduate students with an average age of 22 years. Four participants were unable to complete the calibration. Thus, the valid sample was composed of 94 people. The participants were randomly assigned into one of three groups: the fixation region hint group (31 participants); the key region hint group (32 participants); and the control group (31 participants).

#### 3.1.2. Experimental design

The independent variable was the hint region. The hint regions are illustrated in Fig. 6. White and gray background colors alternated every 500 ms in the animated diagrams. The dependent variable was the success rate.

#### 3.1.3. Procedure

The participants were randomly assigned into one of three groups, and the procedure was identical to that of the first experiment.

### 3.2. Results

The eye movement records revealed that the stimuli treatments were effective in guiding attention. The dwell time percentages were highest in the hinted regions for both the fixation region and key region hint group participants. The means, SDs, and ranges of the problem solving time (in seconds) for each group are shown in Table 4. The mean problem solving time of the fixation region hint group was 268.21 s; for the key region hint group and the control group, the times were 201.06 and 231 s, respectively.

The problem solving success rates by group are shown in Fig. 7 and Table 5. A chi-squared test revealed that the difference between the groups was significant ( $\chi^2(2, N=94)=6.651, p < 0.05$ ). Using an overall correct percentage of 34% as the standard for comparison, the success rate was 19.4% for the fixation region hint group and 50% for the key region hint group. The latter

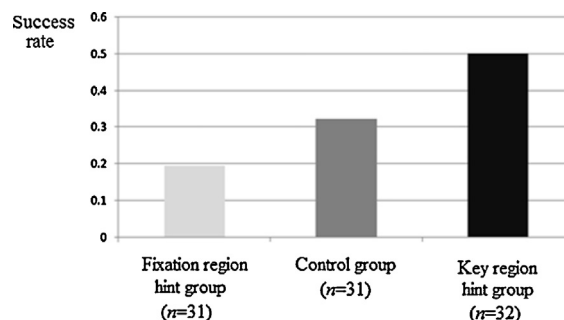


Fig. 7. Comparison of problem solving success rates across groups.

**Table 5**

The number of people and the problem solving success rates, adjusted residual marked in the parentheses by group.

	Fixation region hint group		Control group		Key region hint group		Overall	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>N</i>	%
Successful	6	32.3 (.3)	10	19.4(−2.1)	16	50.0 (2.3)	32	34
Unsuccessful	25	67.7(−.3)	21	80.6 (2.1)	16	50.0(−2.3)	62	66
Total	31	100	31	100	32	100	94	100

group was obviously higher than former group. The success rate for the control group was 32.3%, which was not significantly different from the overall performance.

### 3.3. Discussion

The causality between fixedness averting and representational change was demonstrated by the treatments utilized in experiment 2. The presence of hints in the fixation or key regions led to a significant difference in the success rate between these groups. Thus, our hypothesis was supported. Providing hints in the fixation region decreased the success rate, and hints in the key region increased the success rate. These results indicate that the enforcement of fixedness made representational change difficult, whereas relieving fixedness made this process easier. In conclusion, the results of experiment 2 provide empirical support for the direct influence of fixedness on representational change.

Moreover, the experimental treatment of animating the fixation region of the diagram was effective in decreasing success rates; this finding contrasts with a previous study regarding the influence of an animated tumor diagram in a radiation problem task (Grant & Spivey, 2003). This discrepancy may be due to the animation in the fixation region being an obvious hint to move the matchsticks within this region, thus enforcing fixedness, whereas the animation of the tumor in the radiation problem study did not provide a sufficient hint about the relationship between the treatment and the answer. Nonetheless, the stimuli treatments successfully guided the participants' attention by hinting at the target regions in the present experiment and influenced success rates in a similar manner to previous reports (Grant & Spivey, 2003). Experiment 1 revealed that patterns of gaze directed at the experimental material represented inner thinking processes. Experiment 2 showed that visual material also influenced inner problem solving processes.

## 4. General discussion

Representational Change Theory claims that representational change is the only key to successful insight problem solving. All people are trapped by fixedness, but successful participants are able to transform their representations. The present study proposed a Dual Factors theory in which fixedness averting is also critical to the insight problem solving process. Successful problem solvers were distinguishable by their representational change, which was due to their failure to deeply engage in fixedness. In the present study, two experiments with two designs were used to verify this assumption. In the first experiment, a quasi-experimental design was utilized to examine the eye movements of participants during the matchstick arithmetic problem. The percentage of time spent gazing at the fixation region (i.e., the III on the left side of the equal sign) was significantly reduced in the successful group compared to the unsuccessful group. Guidance of attention was used as the treatment in the second experiment. Providing a hint in the key region was found to increase the rate of success, whereas providing a hint in the fixation region decreased the rate of successful problem solving. Representational Change Theory claims that the transformation of the inappropriate representation is the key to solving insight problems. This principle of Representational Change Theory has been extended by the results of the present study. The results from both of our experiments indicate that a second factor, fixedness averting, is as important as representational change in the insight problem solving process.

Representational Change Theory claims that people who transformed their initial representation appropriately would eventually be successful problem solvers (Knoblich et al., 2001); fixedness averting and correct representational change are simultaneous occurrences, and the former is subset of the latter. However, our study claims that the role of fixedness averting should be distinguished in the process of problem solving. Rather than being a simultaneous occurrence, sequential relationships are assumed to lie between fixedness averting and activating key problem solving knowledge. The eye movement data are quite consistent with the hypothesis that successful participants know to avoid invalid logic at the beginning of the insight problem solving process, which is, consequently, helpful to representational change.

These results support the notion that extraordinary strategies, such as fixedness averting, are effective in insight problem solving. Our study also demonstrates that insight problem solving involves different creative abilities. Gilhooly and Murphy (2005) found that insight problem solving performance is correlated more with the ability to generate a variety of responses than with general problem solving. Insight problem solving requires flexibility. Mednick (1962) associative theory of the creative process claims that individuals tend to respond more strongly to typical stimuli. However, among creative individuals, this pattern is diminished. Successful insight problem solvers might experience this inner process in the same manner

as highly creative people. Because the association of the inappropriate solution was weaker (i.e., low fixation intensity), the retrieval of atypical but correct solutions was easier among successful problem solvers during later processing.

The influence of fixedness on problem solving has been proposed in previous research studies. In a study of the water jar problem, the participants were first able to successfully answer the questions with certain methods, and half of the participants failed on the tasks that required only simple methods (Luchins, 1942). These results indicate that mental set provided a strong barrier to the problem solving process in the latter task. Another example is functional fixedness: in the candle problem, individuals tend to use the box in the role of its typical function as a container. This usage leads to stubborn thoughts about the common function of the box and a failure to solve the problem (Duncker, 1945). Mental sets and functional fixedness are barriers to insight problem solving, as demonstrated by the phenomenon of fixedness observed in the eye movement records of the present study.

Because successful problem solvers were better at fixedness averting, and because fixedness comes from previous experience, our results should be applied in pedagogically grounded situations to enable the analysis of previous knowledge to break misconceptions while learning new concepts. Additionally, we found that hinting at fixation or key sections can produce differences in problem solving. With this idea, teachers can directly note incorrect concepts or list counterexamples accordingly for students (Murray & Byrne, 2013) to help them avoid fixedness in educational settings. It can also be used to note key concepts while acquiring new knowledge or to give hints that reinforce uncommon but correct representations (Gibson, Dhuse, Hrachovec, & Grimm, 2011).

Fixedness averting is critical to insight problem solving. In research studies on verbal insight problem solving (Patrick & Ahmed, 2014), problem solving skills have been demonstrated to improve through teaching. For example, when searching for ambiguous words, the passing rate of verbal insight tasks was increased by providing heuristics to participants. Therefore, students can also gain strategies for fixedness averting through training. We suggest that training on fixedness averting should involve conscious reflective judgment of fixedness or assumptions of insight problem solving for individuals. The ability of reflective judgment is also one of the core skills of critical thinking (Dwyer, Hogan, & Stewart, 2014) and is an important ability that is encouraged in education innovation (Chang, Li, Chen, & Chiu, in press). In future research studies, the effect of reflective judgment training or courses should be investigated to determine if the ability to avert fixedness can be promoted by analyzing the fixedness of problems or by self-inspecting suppositions.

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