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Examining the applicability of representational change theory for remote associates problem-solving with eye movement evidence

Po-Sheng Huang[a,*], Cheng-Hong Liu[b], Hsueh-Chih Chen[c]

[a] Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, Taiwan, ROC
[b] Department of Educational Psychology and Counseling, National Tsing Hua University, Taiwan, ROC
[c] Institute for Research Excellence in Learning Sciences, Chinese Language and Technology Center, Department of Educational Psychology and Counseling, National Taiwan Normal University, Taiwan, ROC

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ABSTRACT

Remote associates problems are a significant measuring tool for the creative process. Scholars have argued that remote associates problems and insight problems share similar core processes. However, there is little empirical evidence for their similarities. The main purpose of this study is to examine the applicability of Representational Change Theory (an insight theory) for remote associates problem-solving. This study manipulated the occurrence position of the keyword of a remote associates problem to alter the constraint relaxation in the problem. The problems were divided into three kinds, namely Keyword-in-Front (KF), Keyword-in-Middle (KM), and Keyword-in-Back (KB) problems. Individuals' eye movements were recorded during problem-solving. The results indicate that the solution rates of KM problems are higher than that of KB problems. Further, when individuals solved KF or KB problems, they had more regression counts and spent longer dwell time on the fixation region than on the key region. However, more time was spent on the key region as well as more regression counts when one was solving KM problems than the other two problems. The results of this study support the applicability of Representational Change Theory in the solving process of remote associates problems.

1. Introduction

During the formation of creative ideas, two things that are seemingly irrelevant are often combined to produce practical and valuable concepts and products. Mednick (1962) put forward the associative theory to explain the process that one associates remote concepts to meet special needs or achieve certain purposes. Further, Mednick (1962, 1968) designed remote associates problems to measure the individual ability of remote association and creative potential. Nowadays, there are still many scholars using remote associates problems in related researches to evaluate one's creativity (e.g. Brodt, Pöhlchen, Täumer, Gais, & Schönauer, 2018; Colzato, de Haan, & Hommel, 2015; Cranford & Moss, 2012; Huang, 2018; Lin & Shih, 2016; Wu, Chang, & Chen, 2017).

Some scholars believe that remote associates problems and insight problems are of the same type since they share similar characteristics of creative problems. They both have limited solution, belong to convergent problems, and involve the individual ability of convergent thinking (Brophy, 2000; Colzato et al., 2015; Hommel, 2012; Ritter, Abbing, & Van Schie, 2018; Shen, Hommel,

* Corresponding author at: Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, No.43, Keelung Rd., Sec.4, Da'an Dist., Taipei City 10607, Taiwan, ROC.
E-mail addresses: poshenghuang@mail.ntust.edu.tw (P.-S. Huang), chenghongliu@mx.nthu.edu.tw (C.-H. Liu), chcjyh@ntnu.edu.tw (H.-C. Chen).

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Yuan, Chang, & Zhang, 2018). The comparison between remote associates problems and insight problems can be seen mostly on theoretical statements (Ben-Zur, 1989; Bowden & Jung-Beeman, 2003a, 2003b; Lubart, 1994), or through evidences from correlational studies (Ansburg, 2000; Huang, Chen, & Liu, 2012; Lee, Huggins, & Therriault, 2014; Schooler & Melcher, 1995). There is insufficient direct evidence that demonstrates the similarities in the solving processes of these two creative problems. If the two creative problems share similar problem-solving processes, then, the theory used to explain insight problem-solving, such as Representational Change Theory, should be able to effectively explain and predict remote associates problem-solving. In recent years, along with the development of eye tracking technology, eye tracker has been widely used to explore the cognitive thinking process, especially the solving process of general or insight problems (Chen, Peng, Tseng, & Chiou, 2008; Grant & Spivey, 2003; Jones, 2003; Knoblich, Ohlsson, & Raney, 2001; Ming, Tong, Yang, Qiu, & Zhang, 2014; Tseng, Chen, Chen, Sung, & Chang, 2014). This study, therefore, aims to examine whether the Representational Change Theory is applicable to remote associates problem-solving. Indicators for eye movements will be used as evidence for the similarities and differences between these two creative problems.

1.1. Theoretical basis of remote associates problems

According to the associative theory, Mednick (1962) defined creativity as a process during which one associates seemingly irrelevant or remotely related concepts for special needs or purposes. The inspiration and creation of many concepts and products are achieved by way of remote association.

However, not everyone can effectively form a remote association and achieve a creative response. Each individual owns different knowledge structure, differs in the number of conceptual association, has diverse cognition or personality style, and chooses different associative responses. Thus, the creativity of the products differs from one to another (Mednick, 1962).

1.2. Remote associates problem

The associative theory provides a new theoretical direction for research studies on creativity. Mednick (1962, 1968) compiled 60 remote associates problems based on associative theory, which constitute two forms of remote associates tests (RAT), each consists of 30 problems. Every problem includes three words (e.g., "*same, head, tennis*"). The participants are asked to find out the target word related to the three words (the solution for the example is "*match*"). The number of correct responses for the 30 problems represents one's ability of remote association. The reliability and validity of the scoring have been well established (Datta, 1964; Mednick, 1963). Furthermore, several researchers have compiled different forms and languages of remote associates problems according to their research purposes (e.g. Bowden & Jung-Beeman, 2003a; Chermahini, Hickendorff, & Hommel, 2012; Huang, 2014; Huang et al., 2012; Sio & Rudowicz, 2007; Wu & Chen, 2017).

Although the concept of remote association, as well as its corresponding measurement, has been constantly being developed since 1962. The remote associates problems are still being used widely as a measurement of creative potential and creative ability due to the advantages of brief implement time, easy to carry out, limited correct responses, and objective scoring. Also, researchers can choose the level of difficulty of the remote associates problems based on the characteristics of the individuals or the specific needs of the studies (e.g. Colzato et al., 2015; Cranford & Moss, 2012; Lin & Shih, 2016). Above all, it could indicate the significance and importance of the remote associates problems on the creativity studies.

1.3. The solving processes of remote associates problems and insight problems

Insight problems and remote associates problems are categorized as close-ended creative problems (Wakefield, 1992) and are regarded as a measurement of convergent thinking abilities since both have a limited solution (e.g., Brophy, 2000; Colzato et al., 2015; Hommel, 2012). This study attempts to compare the similarities of these two problems by examining whether the theory for insight problems is applicable to the processes of remote associates problems. It is, therefore, necessary to introduce the theory about insight problems first before comparison.

1.3.1. Insight problem and insight theory

Creativity is explained from the perspective of "insight" in Gestalt, stating that insight is a process during which one "suddenly perceives useful or appropriate relationship" (Kohler, 1929). Individuals are unable to explain the process during which one suddenly perceives the solution (Metcalfe, 1986) and often accompanies with an "Aha!" experience (Ohlsson, 1984). Further, Mayer (1995) proposed that insight can be produced by reorganizing information, reconstructing problems or removing the dominant but inappropriate knowledge and experience. Sternberg and Davidson (1995) believed that insight is often produced by selectively encoding (activating the information related to the problems), comparison (comparing the relatedness of existing knowledge and problems) or combination (combing the information that seems irrelevant) from the new perspective.

Many researchers have put forward the properties that are essential to an insight problem based on their definitions of "insight", including impasses encounter and "Aha!" experiences. Firstly, in the initial of solving insight problems, the dominant representation which activated by the individual often misleads to the wrong direction, which results in impasses and not getting the correct answers (Dominowski & Dallob, 1995; Kaplan & Simon, 1990; Schooler, Ohlsson, & Brooks, 1993). Secondly, when one jumps out of the dominant knowledge or representations of the problem, the answers appear and accompanied by an "Aha!" experience (Schooler et al., 1993). In brief, one often misleads by a wrong knowledge representation or strategy at the beginning of problem-solving, for which an impasse is encountered, but has no clue on how to solve the problem. After some time of incubation, the impasse is broken,

and the solution is realized with an "Aha!" experience.

Some scholars propose the Representational Change Theory in explaining the processes of insight problems (Knoblich, Ohlsson, Haider, & Rhenius, 1999, 2001; Ohlsson, 1992). According to the theory, individuals fail to solve the problem when they activate the dominant knowledge or representation of the problem. If they continue solving the problem with this representation, they will run into an impasse. Only when the individuals alter their activated representation or knowledge to the correct one, the problems will be solved and insight occurs. Knoblich et al. (1999); Knoblich et al., 2001 further mentioned that dominant representation can be changed through the process of constraint relaxation and chunk decomposition. Constraint relaxation refers to the reduction of unnecessary and unrelated activation, while chunk decomposition means the decomposing of knowledge or concepts into meaningful units, such as breaking down a phone number into single figures.

The viewpoints of Representational Change Theory have supported by many empirical evidence using different types of insight problems (Öllinger, Jones, & Knoblich, 2013; Jones, 2003; Knoblich et al., 1999, 2001; Ohlsson, 1992; Öllinger, Jones, & Knoblich, 2006; Tseng et al., 2014). In a research by Knoblich et al. (1999), four different types of matchstick problems were used to examine the effect of constraint relaxation and chunk decomposition on insight. Each of the problems required the participants to move only one matchstick (but not to remove it) to make the equation correct. (1) Type A problem involves value constraint (numeral movement only) and loose chucks. For instance, to solve the matchstick problem of "*VI = VII + I*", only one matchstick of the numeral "*VII*" is needed to be moved to the numeral "*VI*" to form the correct equation of "*VII = VI + I*". Only the value ("*VII*" and "*VI*") is needed to be changed and the combination of numerals is relatively loose. (2) Type B problem involves value and operator constraints as well as relative intermediate chunks. For example, to solve the problem of "*I = II + II*", one matchstick from the operator " + " is needed to be moved to the first numeral "*II*" to form the correct equation of "*I = III - II*". The value and operator are needed to be changed and the decomposition of Type B problem is relatively more difficult than Type A problem. (3) Type C problem involves operator and tautology constraints as well as intermediate chunks. Take the matchstick problem of "*III = III + III*" for example, one of the matchsticks from the plus sign " + " needs to be rotated to make it an equal sign " = " to form the correct equation of "*III = III = III*". The operator and tautology are needed to be changed and the decomposition of plus sign is also relatively more difficult than Type A problem. (4) Type D problem involves only value constraint but tighter chunk. In solving the problem of "*XI = III + III*", one of the matchsticks from the numeral "*XI*" needs to be moved to becoming the numeral "*VI*" to form the correct equation of "*VI = III + III*". Only the value is needed to be changed but the chunk of numeral "*XI*" is tighter and the decomposition is more difficult than three other problems. The results indicated that the solution rate of Type A problem (single constraint) is higher than those of Type B and C problems (both involve two constraints), which reveals the impact of the constraint relaxation on insight. Moreover, the solution rate of Type A problem (loose chunk) is significantly higher than that of Type D problem (tighter chunk), which supported that the influence of chunk decomposition on insight. Both results show evidence of changing representation through constraint relaxation or chunk decomposition would help solvers overcoming impasses and gain the insight.

1.3.2. The comparison of insight and remote associates problem-solving

Some scholars claim that remote associates problems and insight problems share similar problem-solving processes. Bowden and Jung-Beeman (2003a) analyzed the solving process of remote associates problems and found that, first, both problems will mislead the individual with dominant yet wrong representations. During the solving process of remote associates problems, one often gets stuck in the easy retrieval responses and fails to get the solution. Novel and remote ideas need to be connected to solve the problem. Second, individuals are often unable to state the process of problem-solving (Ben-Zur, 1989). Third, "Aha!" experience appears after solving the problem (Bowden & Jung-Beeman, 2003b). Moreover, Mednick (1962) proposed the concept of Associative Hierarchy to explain individual differences in the performance of creativity. Individuals with steep associative hierarchy tend to form strong associations among closely related concepts and are less likely to link remotely concepts, further result in poor performance in creativity. For those with flat associative hierarchy, they can not only associate closely related concepts but also remotely non-dominant concepts. Therefore, they are more likely to be creative. In other words, closely related concepts are retrieved spontaneously by individuals with steep and flat associative hierarchy, mislead them to inappropriate knowledge representation and fail to solve the remote associates problems. However, those with flat associative hierarchy can eliminate the influence of dominant concepts by associating remotely related concepts and are more likely to produce creative ideas. But for those with steep associative hierarchy are less likely to retrieve remotely related concepts. In brief, the spontaneous association of closely dominant concepts will lead individuals to an impasse, which prevents them from solving the problem. For those with flat associative hierarchy, they will be able to produce creative ideas by changing the representation and associating with remote concepts. In addition, Lubart (1994) pointed out that among the three ways of insight proposed by Sternberg and Davidson (1995), the selective combination is conceptually similar with remote association. Both describe the process of combining diverse concepts.

As for empirical evidence, many correlational studies have found significant positive relationships between remote associates problems and insight problems (Ansburg, 2000; Huang et al., 2012; Lee et al., 2014; Schooler & Melcher, 1995). Huang (2017) further recorded and analyzed the eye movements of individuals when they solved remote associates problems, the results found that the eye movements are similar to those in insight problem-solving and supported the viewpoints of Representational Change Theory. Like insight problem, the solving process of remote associates problem will also experience the insight process of encountering impasses and escaping fixation. However, as Huang's research does not involve experimental manipulation, it only records the process of solving remote associates problems of individuals, so it is susceptible to be affected by the characteristics of remote associates problems. In addition, according to Representational Change Theory, problem solvers can change their representation and attain insight by the mechanism of constraint relaxation and chunk decomposition (Knoblich et al., 1999, 2001). However, the results of Huang's research cannot provide the mechanism evidence of how problem solvers change their representation. Because Huang's

research is insufficient for the interpretation of representational change mechanism, this study further overcomes the inferential restriction in Huang's study by manipulating the position of keyword of remote associates problems, and alters the constraint of the problem to test whether the individual can change the representation through the mechanism of constraint relaxation, so as to gain insight.

Since the eye tracker is widely used in the research of insight and remote associates problems (Chen et al., 2008; Huang, 2017; Jones, 2003; Knoblich et al., 2001; Ming et al., 2014; Tseng et al., 2014) to effectively reflect the possible problem-solving process. The dwell time and regression count are two significant eye movement indicators (Chen, Lai, & Chiu, 2010; Duchowski, 2007; Rayner, 2009; Underwood, 2005). The dwell time in a particular region represents the time needed to comprehend the information on this region and reflects the importance of this information in reading or problem-solving, thus attracting individuals' attention. While regression count represents the reexamination and re-reading of the previously processed information, reflecting that the information in this region may be an important key to comprehend the text. Or when the working memory span is unable to contain all the information, individuals will have more regression and re-reading of information in this region. Given that the eye movement indicator can effectively reflect individuals' problem-solving process, especially in dwell time and regression count, it represents the attention and processing of the individual to the key information. Therefore, in addition to collecting the solution rates of the individual's response to the remote associates problems, this study also recorded the eye movements of the individual when solving the problem, as a representative indicator of the problem-solving process.

2. Predictions of this study

From the theoretical perspective and correlational evidence, remote associates problems and insight problems are regarded as the same type of creative problem and share similar process of problem-solving (Ben-Zur, 1989; Bowden & Jung-Beeman, 2003a, 2003b; Lubart, 1994). However, except for the study of Huang (2017), few have provided direct evidence to compare the solving process of the two problems.

This study aims to examine the applicability of Representational Change Theory (which used to explain the insight process) for remote associates problem-solving. According to the theory, individuals can change representations through constraint relaxation or chunk decomposition (Knoblich et al., 1999, 2001). Thus, we attempt to examine the influence of constraint relaxation on problem-solving by manipulating the occurrence position of keyword in remote associates problems. By altering the position of keyword will enable the individual to reduce the probability of activating irrelevant knowledge and remove the constraint of concept associations, further affect their solving process. In recent years, many empirical studies on problem-solving have confirmed that eye movements can effectively reflect one's cognitive solving process and provide more precise indicators other than behavior data (Chen et al., 2008; Grant & Spivey, 2003; Jones, 2003; Knoblich et al., 2001; Ming et al., 2014; Tseng et al., 2014). Therefore, in this study, not only the behavior data of the solution rate but also the corresponding eye movements will both be recorded while participants are solving remote associates problems.

This study adopted remote associates problems (for instance, "*doctor, nurse, tour guide*") compiled and adopted by Huang (2014, 2017). The first two words of each problem ("*doctor, nurse*") are fixation words, which belong to the same conceptual category. They tend to lead individuals to stick to the associations of the conceptual category (the first associations that they form are all related to hospitals in this case) and encounter an impasse. Individuals who can escape the fixation of the conceptual category and form associations with the third word ("*tour guide*" in this case; the third word differs from the first two words in conceptual category and it is the keyword for solving the problem) will successfully solve the problem. Through the change of concept representations, the insight will emerge. If the position of keyword is changed and it is put in the middle of the two fixation words (Keyword-in-Middle, KM) ("*doctor, tour guide, nurse*" in this case), individuals will be less likely to be influenced by the concepts of the same category. Instead, they are more likely to find out the association between "*doctor*" and "*tour guide*". Therefore, they will have a higher possibility of solving the problem successfully. Conversely, if the fixation words appear one after another, either in the context of Keyword-in-Back (KB, "*doctor, nurse, tour guide*" in this case) or in the context of Keyword-in-Front, (KF, "*tour guide, doctor, nurse*" in this example), the individual will have a higher chance of getting stuck in the association around the concepts of the same category; hence, encounter an impasse and have a lower possibility of solving the problem.

This study predicts that (1) as for the solution rate, placing the keyword between the two fixation words (KM problems) will decrease the chance that individuals encounter an impasse which occurs when two fixation words appear one after another (KF or KB problems). The KM problems will decrease the constraint on associations, and reduce the probability of activating irrelevant knowledge. Thus, the solution rate of KM problems will improve compared to KF and KB problems (Hypothesis 1–1). As for the eye movements, this study predicts that (2) keyword of remote associates problems appearing in different positions will exert an impact on the regression counts (Hypothesis 1–2) and on the fixation time (Hypothesis 1–3) of an individual for keyword and fixation words. If the keyword is positioned between the two fixation words (KM problems), the individual is less likely to be influenced by fixation words which will reduce the chances of encountering an impasse. During this process, the regression count for fixation words will be less than that for the keyword (Hypothesis 1–2a); the percentage of dwell time for fixation words will be shorter than that for the keyword (Hypothesis 1–3a). If the fixation words in the problem appear one after the other (KF or KB problems), the individual will be more likely influenced by the fixation words that appear in succession. Fixation words will be checked repeatedly. Therefore, it is predicted that the times of checking fixation words will be more than that of the keyword (Hypothesis 1–2b), and the percentage of dwell time for fixation words will be longer than that for keyword (Hypothesis 1–3b).

3. Methods

3.1. Participants

In this study, 58 college students (28 males, 30 females) with normal vision (with or without correction) participated in the study. Their average age is 26.03 with a standard deviation of 6.10. They were invited to solve 12 remote associates problems during which, their eye movements were recorded in a dynamic, natural, and undisturbed manner.

3.2. Design

The experiment adopted a 2 × 2 × 3 mixed factorial design with three independent variables. The performance variable is a between-subject variable, consisted of a high and low performance group, which were divided according to the mean ($M = 0.63$) of the solution rate for the 12 remote associates problems. The region variable was divided into fixation region and key region, depending on whether the words in the problem are fixation words or keyword. The keyword position variable was divided into Keyword-in-Front (KF), Keyword-in-Middle (KM), and Keyword-in-Back (KB) problems based on the location of the keyword in the problem. The last two are within-subject variables. The dependent variables are the indicators for the solution rate and eye movements, including dwell time (in seconds), fixation time, fixation duration (in millisecond), regression counts, and percentage of dwell time.

3.3. Materials and apparatus

3.3.1. Remote associates problems

The experiment adopted the 12 remote associates problems formulated and used by Huang (2014, 2017). Each problem consisted of three words as stimuli (such as "*doctor, nurse, tour guide*"), two of which belong to the same conceptual category ("*doctor*" and "*nurse*" are all related to hospitals) which will lead the participants to associate with a particular conceptual category (such as "*hospital, operation, surgery, medical treatment …*") during problem-solving. Participants who continue to form associations with the two words of the same conceptual category will eventually fall into a fixation, encounter an impasse, then resulting in failure to solve the problem (the answer is "*profession*" or "*expertise*"). The two words that often lead participants to a fixation are defined as "fixation region", as shown in Fig. 1. On the other, the third word in the problem belongs to a different conceptual category. During the process of problem-solving, participants need to get out of the conceptual category of the fixation words and form an association with the keyword. This will decide whether the participant could escape the fixation and solve the problem successfully. Therefore, the keyword is defined as "key region".

The purpose of this experiment is to test whether Representational Change Theory can be used to explain the process of solving remote associates problems. The effect of constraint relaxation on problem-solving was manipulated by the position of keyword, and how it exerts an impact on the solution rate and eye movements was observed. During the manipulation of keyword position variable, the keyword was positioned in either KF (such as "*tour guide, doctor, nurse*"), KM (such as "*doctor, tour guide, nurse*"), or KB (such as "*doctor, nurse, tour guide*") problems. The varying position was done to influence the way participants form the conceptual association, and hence to affect the possibility of getting stuck in an impasse. Four out of the 12 problems were selected at random to constitute KF, KM, or KB problems. Each participant completed 12 problems, four KF, four KM, and four KB problems. All problems were presented at random in the Experiment-Builder software.

In order to further compare participants' eye movements from fixation words and keyword, an AOI (Area of Interest) for the three words was drawn within a 200 × 100 pixel square to define the region variable. Since there were two fixation words in the problems used in this experiment, the average of the eye movement indexes for the regions of the two fixation words were used to represent individual eye movement indicator for the fixation region. In this way, the difference in the size of the area was avoided to prevent its influence on the analysis of the eye movement indexes.

3.3.2. Eye-tracking system

During the experiment, an Eyelink 1000 eye tracker (SR Research, Mississauga, Ontario, Canada) with a Dell OptiPlex Gx620 computer, and a Chimei 19PS monitor were used to record experimental data. The Eyelink 1000 eye tracker uses a pupil-cornea eye tracking method to record the position where the eye fixes on the screen by tracking eye movement. The sampling rate was set at 1000 Hz, which means that the sampling was at 1000 times per second. The resolution was set at 0.01°. The delay time for the access to the eye position data was 2 msec. The average position error of fixation was 0.15° (less than the general error by 0.25° to 0.5°). In this experiment, the participants viewed the problems in the screen using both eyes at the same time. Since the simultaneous

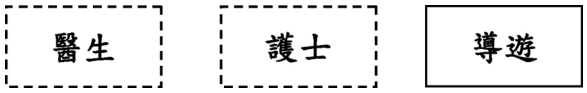


Fig. 1. An Example of Keyword-in-Back Remote Associates Problem from Huang (2017).
Notes: The translations of the words are "*doctor*", "*nurse*," and "*tour guide*" sequentially. Squares with dotted lines represent the fixation region; the square with solid lines, represent the key region.

recording of two eyes probably leads the left and right eyes to be less focused, only monocular eye movements were recorded. The system was mainly set to record the eye movements of the right eye. Only when the right eye could not be pinpointed by the device, was the movements of the left eye recorded.

3.4. Procedure

The experiment was conducted individually. Before the formal phase of the study, participants were asked to sit about 80 cm away from a 19-inch screen on which remote associates problems were displayed. A straight line is formed from the center of the screen to the participants' eyes. The participant was asked to put his chin on the head support of the eye tracker. After, the examiner adjusted the micro-camera to its proper position and recorded the movement of the right eye at a sampling rate of 1000 Hz. Next, a nine-point Calibration Test was conducted. They were asked to fix their gaze at the black spots that appear at different positions on the screen to calculate the values of the pupil-cornea position to that of the visual material. If the participant passed the Calibration Test, the Validation Test will then be performed using the same procedure to check the consistency with the previous calibration test. After confirming that the eye-tracking device could accurately record the eye movements of the participants, the examiner started the practice phase.

The purpose of the practice phase was mainly allowing participants to be familiar with the procedures. Displayed on the screen were four remote associates problems randomly presented. Participants were asked to press the spacebar and to verbalize their response once they thought of the answer. The experimenter will judge its correctness based on the response provided by the participants. If the answer was correct, they would proceed to the next problem; if the answer was incorrect, they would return to the previous problem to try to solve it again. The maximum allowable time to solve a problem was 3 min. When the time was up, participants would have the chance to report their response again before they went on to solve the next one.

Confirming that participants had no problem with the procedure, the formal experiment was started. They were asked to solve 12 remote associates problems using the same procedures as that of the practice phase. The entire experiment took 40–50 minutes. After the experiment, the research purpose and procedure were introduced, each of the participants was given 200 New Taiwan Dollars as a token of gratitude for their participation.

4. Results

Among the 58 participants, the eye movements data of 7 participants were deleted because of high calibration errors. The data of 51 participants were analyzed in total.

4.1. The solution rate of remote associates problems with different keyword positions

The result of one-way analysis of variance (ANOVA) showed that the variables of keyword position had a marginal effect, F (2, 100) = 2.46, p = 0.091, MSE = 0.054, and η_p^2 = 0.047. The Post hoc results revealed that the average solution rate for KM problems (M = 0.67, SD = 0.23) is significantly higher than that for KB problems (M = 0.57, SD = 0.30). There is no difference between KF problems (M = 0.64, SD = 0.24) and the other two types of problems (as Table 1).

4.2. Dwell time, fixation times, and average fixation duration for remote associates problem-solving

One-way ANOVA was conducted, with the keyword position as the independent variable, and dwell time, fixation times, and average fixation duration as the dependent variables. The results show that there is no significant difference among the dwell time for three different types of problems, F (2, 100) = 1.16, $p > 0.05$, and MSE = 1373.08.

In addition, the keyword position variable has no main effect on fixation times [F (2100) = 1.35, $p > 0.05$, and MSE = 7824.67] and on average fixation duration [F (2, 100) = 1.72, $p > 0.05$, and MSE = 0.288]. This means that the position of keyword does not exert an impact on dwell time, fixation times and average fixation duration during the process in which the participants solved the problems.

Table 1
Descriptive Statistics of Solution Rate, Dwell Time, Fixation Times, and Average Fixation Duration for Different Types of Problems.

	Solution Rate		Dwell Time		Fixation Times		Average Fixation Duration	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
KF problem	0.64	0.24	92.99	39.88	216.98	98.11	303.45	60.53
KM problem	0.67	0.23	85.55	38.11	196.04	93.92	303.86	55.99
KB problem	0.57	0. 30	96.50	48.67	223.60	126.49	307.53	61.90

Notes: KF, KM, and KB is the abbreviation for the Keyword-in-Front, Keyword-in-Middle, and Keyword-in-Back.

Table 2
Descriptive Statistics on the Regression Counts in Performance, Keyword Position, and Region Variables.

		KF problem		KM problem		KB problem	
		Key Region	Fixation Region	Key Region	Fixation Region	Key Region	Fixation Region
Low performance group, n = 22	*M*	29.59	36.03	40.10	25.49	34.72	44.69
	SD	13.30	14.90	16.51	10.32	15.81	15.67
High performance group, n = 29	*M*	22.30	26.94	29.41	18.77	16.04	22.13
	SD	10.13	12.05	15.05	9.53	8.14	9.69

Notes: KF, KM, and KB is the abbreviation for the Keyword-in-Front, Keyword-in-Middle, and Keyword-in-Back.

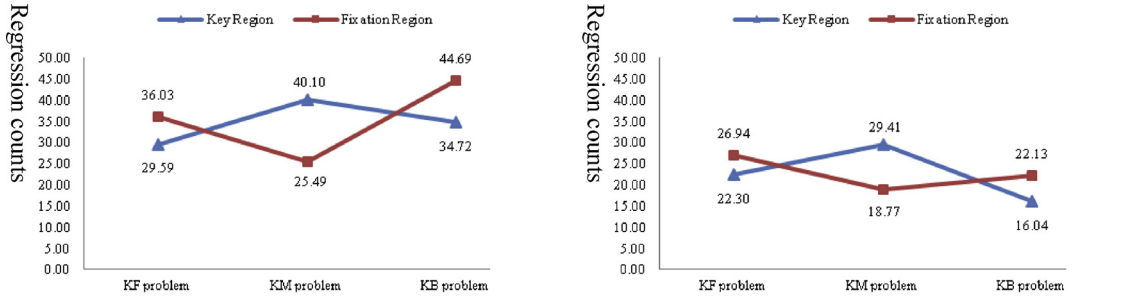
4.3. The regression counts in different AOIs of remote associates problems

A three-way ANOVA was conducted with the performance, keyword position and region variables as independent variables and the regression counts as the dependent variable. The related descriptive statistics are shown in Table 2.

The results reveal that there is a three-way interaction effect (as Table 4), F (2, 98) = 5.67, p < 0.05, MSE = 18.33, and η_p^2 = 0.104. Furthermore, as shown in Fig. 2a, results of the simple interaction effect indicate that for the low performance group, there is an interaction effect between the keyword position and region variables, F (2, 98) = 106.06, p < 0.05, and MSE = 18.33. The regression counts of problem solvers for the words in the fixation region (Ms = 36.03, 44.69) are greater than that for the words in the key region (Ms = 29.59, 34.72) when they solved KF and KB problems, Fs (1, 49) = 28.25, 108.51, ps < 0.05. However, in the process of solving KM problems, the regression counts of the participants for the words in the key region (M = 40.10) are greater than those for the words in the fixation region (M = 25.49), F (1, 49) = 111.62, and p < 0.05. On the other, for the words in the key region, the regression counts during KM problem-solving are greater than those during KF problem-solving, F (2, 98) = 3.91, and p < 0.05. For words in the fixation region, the regression counts during KB problem-solving is greater than KF problems, both are also greater than KM problems, F (2, 98) = 17.51, and p < 0.05.

For high performance group, there is also an interaction effect between the keyword position and the region variables, F (2, 98) = 67.89, p < 0.05, and MSE = 18.33. Further tests for the simple interaction effect show that the regression counts for the words in the fixation region (Ms = 26.94, 22.13) are greater than those for the words in the key region (Ms = 22.30, 16.04) in solving KF and KB problems, Fs (1, 49) = 19.29, 53.28, and ps < 0.05. In solving KM problem, the regression counts for the words in the key region (M = 29.41) are greater than those for the words in the fixation region (M = 18.77), F (1, 49) = 77.90, and p < 0.05. On the other, for the words in the key region, the regression counts during KM problem-solving are greater than those during KF and KB problem-solving, F (2, 98) = 8.35, p < 0.05. For the words in the fixation region, the regression counts during KF problem-solving are greater than those during KM problem-solving, F (2, 98) = 4.21, p < 0.05. It is worth mentioning that although the trends of interaction between the high performance group and the low performance group at the keyword position and region variables are the same, the difference in the low performance group is more significant.

In addition, the performance variable exerted a main effect, F (1, 49) = 28.85, p < 0.05, MSE = 406.87, and η_p^2 = .371. The low performance group (M = 35.10) has a significantly greater regression counts than the high performance group (M = 22.60). However, neither the keyword position variable (F = 0.095, p > 0.05) nor the region variable (F = 0.70, p > 0.05) has any main effect.



(a) Regression Counts for the Low Performance Group

(b) Regression Counts for the High Performance Group

Fig. 2. Analysis of Regression Counts of the High and Low Performance Groups for the Keyword Position and Region Variables.
Notes: KF, KM, and KB is the abbreviation for the Keyword-in-Front, Keyword-in-Middle, and Keyword-in-Back.

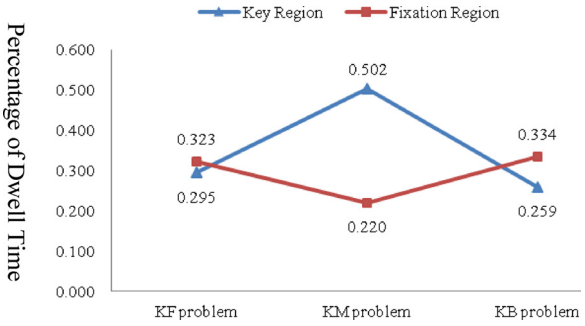


Fig. 3. The Percentage of Dwell Time for Different Regions of Three Types of Remote Associates Problems.
Notes: KF, KM, and KB is the abbreviation for the Keyword-in-Front, Keyword-in-Middle, and Keyword-in-Back.

4.4. The percentage of dwell time in different AOIs of remote associates problems

A three-way ANOVA was conducted with the performance, keyword position, and region variables as the independent variables, and the percentage of dwell time as the dependent variable. The results showed that the three-way interaction effect is not significant, F (2, 98) = 1.87, $p > 0.05$, MSE = 0.006. Further, the interaction effect between the performance and region variables is not significant, F (1, 49) = 1.89, $p > 0.05$, MSE = 0.004. Nor is the interaction effect between the performance and keyword position variables, F (2, 98) = 0.18, $p > 0.05$, MSE = 0.001. Only the keyword position and region variables have an interaction effect, F (2, 98) = 156.32, $p < 0.05$, MSE = 0.006, and $\eta_p^2 = 0.761$. As shown in Fig. 3, tests of simple main effect found that the region variable has a main effect for KF and KB problems, Fs (1, 49) = 4.27, 29.92, ps < 0.05. The percentage of dwell time for words in the fixation region (Ms = 0.323, 0.334) is significant greater than that for the words in the key region (Ms = 0.295, 0.259). For KM problems, the region variable also exerted main effects, F (1, 49) = 321.48, $p < 0.05$. The percentage of dwell time for the words in the key region (M = 0.502) is greater than that in the fixation region (M = 0.220). On the other, for the words in the key region, the percentage of dwell time for KM problems is greater than that of KF and KB problems, F (2, 98) = 159.22, $p < 0.05$. As for the words in the fixation region, the percentage of dwell time for KB and KF problems is greater than that of KM problems, F (2, 98) = 134.94, $p < 0.05$.

For the main effect, the keyword position variable revealed a significant effect, F (2, 98) = 138.17, $p < 0.05$, MSE = 0.001, $\eta_p^2 = 0.738$. The percentage of dwell time for KM problems (M = 0.361) is greater than that for KF problems (M = 0.309), and for KB problems (M = 0.296). The region variable also exerted a main effect, F (1, 49) = 75.76, $p < 0.05$, MSE = 0.004, and $\eta_p^2 = 0.607$. The percentage of dwell time for the words in the key region (M = 0.352) is greater than that for the words in the fixation region (M = 0.292). The performance variable has no main effect, F (1, 49) = 0.10, $p > 0.05$, MSE = 0.002 (Table 3).

5. General discussion

5.1. Implications of the present study

According to previous literature, the remote associates problems and insight problems, which are both used to measure individuals' creative potential, share similar problem-solving processes (Bowden & Jung-Beeman, 2003b; Ben-Zur, 1989; Bowden & Jung-Beeman, 2003a; Lubart, 1994). They are considered as the same type of creative problem (Brophy, 2000; Colzato et al., 2015; Hommel, 2012). However, the arguments are mostly based on theoretical statements or empirical evidence of correlational studies (e.g., Ansburg, 2000; Huang et al., 2012; Lee et al., 2014; Schooler & Melcher, 1995). Direct evidence of problem-solving process for the comparison between these two creative problems is still lacking.

Accumulated evidence has supported that Representational Change Theory can effectively explain the solving process of insight problems (2013, Jones, 2003; Knoblich et al., 1999, 2001; Ohlsson, 1992; Öllinger et al., 2006; Tseng et al., 2014). According to the theory, when an individual starts solving insight problems, the dominant concept or representation will often be activated. However,

Table 3
Descriptive Statistics on the Percentage of Dwell Time in Performance, Keyword Position, and Region Variables.

		KF problem		KM problem		KB problem	
		Key Region	Fixation Region	Key Region	Fixation Region	Key Region	Fixation Region
Low performance group, n = 22	*M*	0.298	0.323	0.497	0.224	0.277	0.319
	SD	0.059	0.040	0.085	0.036	0.083	0.046
High performance group, n = 29	*M*	0.291	0.323	0.507	0.217	0.241	0.349
	SD	0.065	0.039	0.076	0.037	0.056	0.031

Notes: KF, KM, and KB is the abbreviation for the Keyword-in-Front, Keyword-in-Middle, and Keyword-in-Back.

Table 4
The results of ANOVA on the Regression Counts and Percentage of Dwell Time in Performance, Keyword Position, and Region Variables.

	Regression Counts			Percentage of Dwell Time		
	F	*MSE*	η_p^2	*F*	*MSE*	η_p^2
Performance	28.85*	406.87	.371	0.10	0.002	.002
Keyword Position	0.095	253.10	.002	138.17*	0.001	.738
Region	0.70	10.64	.014	75.76*	0.004	.607
Performance × Keyword Position	4.88*	253.10	.091	0.18	0.001	.004
Performance × Region	0.57	10.64	.012	1.89	0.004	.037
Keyword Position × Region	173.53*	18.33	.780	156.32*	0.006	.761
Performance × Keyword Position × Region	5.67*	18.33	.104	1.87	0.006	.037

* $p < .05$.

it is not the key to solve the problem. If it is used continuously, it may lead to an impasse. Individuals can alter the activated representation through the use of constraint relaxation (reducing activation of unrelated knowledge) or chunk decomposition (breaking knowledge or concepts into more meaningful units), further result in escaping fixation and successfully solving the problem (Knoblich et al., 1999, 2001). If remote associates problems and insight problems share similar problem-solving processes, then the Representational Change Theory that can effectively explain the process of insight should also be able to explain the process of solving remote associates problems. Although Huang (2017) research attempts to provide evidence of eye movements to reflect the insight process of encountering impasses and escaping fixation in solving remote associates problem. Due to the fact that Huang's study only recorded the eye movements of individuals, and did not involve any experimental manipulation of variables, it is susceptible to be affected by the characteristics of remote associates problems. Also, it is difficult to draw inferences about the mechanism through which the individual can jump off the fixation and attain insight. Therefore, more direct evidence is still needed to examine the internal mechanism of remote associates problem solving, as a basis for comparing the insight problem-solving.

In this study, constraint relaxation of Representational Change Theory was manipulated by altering the occurrence position of keyword of remote associates problems to examine its effect on the participants' solving process. We predicted that, relative to the problems which two fixation words appear one after another (KF or KB problem), individuals will not get stuck in the fixation and the solution rate will be improved if the keyword of the problem is placed in the middle of the two fixation words (KM problem). The results of present study did reveal that the solution rate of KM problems is higher than that of KB problems, but there is no difference with the KF problems. Hypothesis 1-1 has been partially supported. The findings are consistent with previous studies on insight problems (Knoblich et al., 1999, 2001), and both support the viewpoints of Representational Change Theory. That is to say, the process of constraint relaxation not only effectively improves one's performance of insight problems, but also improves the solution rate of the remote associates problems. It provides the empirical evidence for these two creative problems sharing similar problem-solving processes. It is worth mentioned that, although the solution rate of KF problems is relatively lower than KM problems, but no significant difference was found. We inferred that the possible reason might be that, the keyword appeared in the first place for KF problems, it may possibly reduce the influence of the two fixation words and resulting in a slight increase in their solution rates.

In addition, this study also recorded participants' eye movements. The findings found that the position of keyword can affect the regression counts and viewing time for the words in the key region and fixation region. Hypotheses 1–2 and 1–3 are both supported by the results. When the keyword appeared in the middle of two fixation words (KM problems), the regression counts (Hypothesis 1–2a) and percentage of dwell time (Hypothesis 1–3a) for the word in the key region were greater, which decreased the activation and fixation of irrelevant concepts. But if the two fixation words appear one after another (KF or KB problems), the regression counts (Hypothesis 1–2b) and percentage of dwell time (Hypothesis 1–3b) for the words in the fixation region increased, which enhanced the possibility of irrelevant concept activation and stuck in fixation. It implies that to relax the constraint of the problems through altering the position of keyword will lower the influence of fixation words and effectively reduce the association of irrelevant words, further improve the solution rates of remote associates problems. In other words, the evidence from eye movements also supports that the process of constraint relaxation from Representational Change Theory can effectively explain the solving process of remote associates problems.

Both the behavioral data for the solution rate and eye movement indicators support that Representational Change Theory can also be applied to the solving process of remote associates problems. The relaxation of constraint can effectively change the representations activated by individuals and further increasing the possibility to solve the problems.

5.2. Application and limitation

Previous studies generally lack direct evidence on the comparison of solving process between remote associates problems and insight problems. By manipulating the position of keyword in problems, this study found that the constraint relaxation in Representational Change Theory also exerted an impact on solving performance and eye movements for remote associates problems. The finding supports that Representational Change Theory can also be applied to explain the solving process of remote associates problems as well as insight problems. This study provides direct evidence for the solving process of remote associates problems and clarifies its relationship with insight problem-solving. In addition, different from previous studies that only adopting the solution rate

to examine the application of Representational Change Theory on insight process, this study additionally provided the refined evidence of eye movements for the solving process of remote associates problems.

However, the remote associates problems used in this study belong to the problem with the forms of multiple association. Nowadays, some researchers adopt remote associates problems with a single association of compound word (Bowden & Jung-Beeman, 2003a; Sio & Rudowicz, 2007; Wu et al., 2017). Further studies are needed to explore the difference in the solving process between single and multiple association problems. Moreover, it is suggested that future studies investigate and compare the neural mechanism of solving remote associates problems and insight problems.

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