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The Different Role of Working Memory in Open-Ended Versus Closed-Ended Creative Problem Solving: A Dual-Process Theory Account

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This study examined how working memory plays different roles in open-ended versus closed-ended creative problem-solving processes, as represented by divergent thinking tests and insight problem-solving tasks. With respect to the analysis of different task demands and the framework of dual-process theories, the hypothesis was that the idea generation in a divergent thinking test relies more on associative, effortless system 1 processing, but insight problem solving requires rule-based, resource-limited system 2 processing, in addition to system 1 processing. Since system 1 was suggested to be more active in resource deprivation conditions, Experiment 1 adopted the dual-task paradigm, which increased participants' working memory load. The results showed that divergent thinking performance was enhanced and insight problem-solving performance was hindered. Experiment 2 using the individual differences approach found that individuals' working memory capacity correlated with insight problem solving but not with divergent thinking performance, indicating a possible involvement of system 2 processing in insight problem solving. These findings suggested that open-ended and closed-ended creative problem solving involve different processes and helped to clarify some past inconsistencies when considering the relationship of factors with creativity.

Although both contain the same goal of investigating human creativity, the *psychometric approach*, which mainly focuses on the idea of divergent thinking, and the *cognitive approach*, which is aimed at inspecting the processes of creative problem solving, work in parallel and seldom interact with each other in the creativity research literature (Sternberg & Lubart, 1999; Sternberg, Lubart, Kaufman, & Pretz, 2005). The concept of divergent thinking was first proposed by Guildford (1956) as generating diverse and numerous responses to a given question and served as the theoretical basis for many creativity tests (e.g., Guildford, 1963; Torrance, 1966; Wallach & Kogan, 1965). For example, the examinee was asked to list as many as possible interesting and unusual uses of a brick in the Unusual Uses Test (Guildford, 1956). Fluency (referring to the ability to generate many responses), flexibility (referring to the ability to switch categories between responses), and originality (referring to the ability to generate rarely seen responses according to the norm) were then scored as the indexes[1] of divergent thinking abilities. On the other hand, one of the representative problems investigated in the cognitive approach was an insight

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[1]The fourth index, elaboration, is used especially for a figural question that refers to the degree of elaborating on a drawing by adding detailed decorations.

problem (e.g., the candle problem, Duncker, 1945); problem solvers usually encountered obstacles at first and invented a sudden "Aha!" solution later (e.g., Dominowski, 1995; Ohlsson, 1984). Stages of solving insight problems were proposed (e.g., preparation phase, incubation phase, illumination phase, and verification phase, Wallas, 1926), and processes between insight versus noninsight problem solving were compared (e.g., DeYoung, Flanders, & Peterson, 2008; Gilhooly & Murphy, 2005). The correctly solved insight problems were usually used as an index of creative ability in this approach.

When investigating the relationship of various factors with creativity, researchers used either divergent thinking tests or insight problem tasks as measures of creativity. Inconsistent conclusions were sometimes revealed (Kaufmann, 2003). For example, when considering the relation between creativity and emotion, some researchers found that positive emotion could enhance creativity that used insight problem measure (e.g., Isen, Daubman, & Nowicki, 1987) whereas others found that both positive and negative emotions facilitated creative performance, using divergent thinking to measure creativity (e.g., Adamen & Blaney, 1996). Similarly, some studies investigating the relationship between intelligence and creativity claimed that a certain level of intelligence was required for creativity but that there was no correlation between intelligence and creativity beyond that point (i.e., the threshold theory, for a review, see Runco, 2007) when divergent thinking tests were primarily used. Other researchers found that intelligence exhibited a stable positive correlation with creativity (for a review, see Sternberg et al., 2005). Do divergent thinking and insight problem solving involve the same components or processes of creativity?

According to Wakefield (1989), a divergent thinking task was categorized as a well-defined, open-solution problem, and an insight problem was considered an ill-defined, closed-solution problem. Along this open-versus closed-ended dimension, some researchers believed that divergent thinking was the foundation of solving an insight problem (e.g., Brophy, 1998; Rickards, 1994). In Campbell's (1960, see also Simonton, 1989) two-phase theory of creativity, which was analogous to the evolution of organisms, ideas were generated randomly and blindly (i.e., divergently) in the first phase of creative problem solving (blind variation), in which the quantity and novelty of ideas were important. This phase was followed by a cautious selection process, in which finding a correct and appropriate answer was the main concern (as in a closed-ended insight problem). However, other researchers claimed that both novelty and appropriateness were considered simultaneously in generating ideas when a specific goal existed in a closed-ended creative problem-solving process (e.g., Perkins, 1998; Sternberg et al., 2005). The idea generation processes in a divergent thinking test and in an insight problem-solving task might be essentially different. This study reexamined this issue under the framework of dual-process theory of cognition, showing whether the two aforementioned creativity tasks were influenced by the same cognitive factor (i.e., working memory load) and were related to performers' working memory capacities in similar ways.

A DUAL-PROCESS ACCOUNT

Recently, a set of dual-process theories was proposed independently to account for individual difference performance on widely ranged tasks involving human reasoning, decision making, and judgment (e.g., Evans, 2003, 2007; Gilbert, Pelham, & Krull, 1988; Gilhooly & Murphy, 2005; Kahneman & Frederick, 2005; Sloman, 1996; Smith & DeCoster, 2000; Stanovich & West, 2000). These theories generally assumed that humans possessed two alternative process systems while performing a cognitive task. System 1 (or the heuristic system) was assumed to process information in an associative and effortless manner without capacity limits; system 2 (or the analytic system) involved logical and rule-based processes in which execution relied on cognitive resources.

Some researchers did apply similar dual-process idea to creativity. For example, Kris (1952) considered the primary versus secondary process, Martindale (1995) addressed defocused versus focused attention, and Gabora (2010) proposed a possible neural basis for the shift between processing modes. Supplementary to the previously mentioned theories, whereby researchers generally claimed that creativity involved both processes, this study aimed to specify that the underlying process of idea generation in an open-ended divergent thinking test and in a closed-ended insight problem-solving task might exhibit different involvement of both systems. Although various kinds of divergent thinking tests exist, including some recruiting an assignment to accomplish (e.g., design a useful backpack), the appropriateness or practicability of the responses was generally not required or scored by the tests' open-ended nature. Idea generation in a divergent thinking test was therefore hypothesized to require more associative processing of system 1 in which the quantity and the remoteness of association were emphasized and scored. Generating plausible solutions in insight problem solving additionally required system 2 to simultaneously keep multiple constraints in mind and fulfill the specific solving goal (see also Evans, 2005).

Working memory has been proposed to be a crucial construct to differentiate system 1 from system 2 processing mode (e.g., Stanovich, 1999). It refers to cognitive resources, consciousness, and is essential for executing many cognitive functions including creativity (Vandervert, Schimpf, & Liu, 2007). According to previous findings, individual differences in task performance due to working memory capacity could only be observed when the tasks involved system 2. In addition, system 1 was predicted to be more active when cognitive resources were short than when they were not (e.g., Evans, 2003; Gilhooly, Logie, Wetherick, & Wynn, 1993). For example, participants often used heuristic thinking, which was based on the association of past experiences, when making judgments in a resource-limited situation (Kahneman & Frederick, 2005). The present study thus predicted that (a) unlike their performance in closed-ended creative problem solving, people's performance in divergent thinking would be facilitated rather than hindered when the cognitive resource was reduced; (b) individual differences in performance due to working memory capacity could be observed only in closed-ended creative problem-solving tasks rather than in divergent thinking tests. Two experiments were conducted to test these predictions, respectively.

EXPERIMENT 1

To test the first prediction, a dual-task paradigm was used in Experiment 1, which lowered participants' available mental resources, to investigate the impact of working memory on the two creativity measures. Participants were asked to repeatedly count a series of numbers as a secondary task (e.g., Engle, Conway, Tuholski, & Shisler, 1995) to increase their working memory load while performing either divergent thinking or closed-ended creative problem solving as a primary task.

To compare the difference between the idea generation in open-ended versus closed-ended creative problem solving, the 2-4-6 task (Wason, 1960) was used as the closed-ended creative problem. In the 2-4-6 task, participants were told that "2-4-6" is a number triple that was generated in accordance with a predetermined rule (i.e., ascending numbers), which they were required to discover. They were asked to test a series of triples at their choice (such as 6-8-10) and receive feedback about whether each tested triple was consistent with the correct rule. Based on this feedback, they could generate or revise their hypotheses. These processes involved idea generation, testing, and revising that was essential for creative cognition (e.g., Torrance, 1988; Ward, Smith, & Finke, 1999). More important, the 2-4-6 problem possessed features of insight problem as Dominowski (1995) suggested[2] (e.g., Oaksford & Chater, 1994; Tukey, 1986; Tweney et al., 1980; Vartanian, Martindale, & Kwiatkowski, 2003; Wason, 1977). Participants usually stuck to incorrect hypotheses (e.g., consecutive even numbers) closely associated with the given instance (i.e., 2-4-6) although the answer required no knowledge beyond what those university participants already possessed.

Lien and Lin (2011; Lin, Lien, & Jen, 2005) developed a new type of index, the number of new-perspective hypotheses, for measuring the degree of creativity in the hypothesis-generation process in the 2-4-6 task. Based on Chi's (1997) idea of radical versus weak conceptual change, they proposed that when a hypothesis was revised into one including new concepts or components (i.e., the new-perspective hypothesis), it was considered more creative than one revised within the same conceptual branch (i.e., same-perspective hypothesis). Empirical evidence showed that the number of new-perspective hypotheses effectively predicted the final success of 2-4-6 task (Lien & Lin, 2011) as well as positively correlated with participants' insight problem-solving performance (Lin, 2006). By adopting this classification, the use of the 2-4-6 problem in this study therefore allowed exploration of creativity in the idea generation phase during the closed-ended creative problem-solving process.

The Chinese Version of Creative Thinking Test (CVCTT; Wu, 1998) was designed from subtests of Torrance Test of Creative Thinking (TTCT; Torrance, 1974) with culturally familiar materials and was used to measure participants' divergent thinking abilities. This test consisted of typical divergent thinking problems (i.e., unusual uses and figure completion) and has been developed as a large-sample norm in Taiwan for elementary to graduate students. It also established stable reliability and validity results. The interrater reliability reached .93, and the correlations of indexes with the scores of TTCT were above .50.

According to the previous analysis, it was predicted that participants' abilities in generating creative new-perspective hypotheses in the 2-4-6 task would be hindered in the working memory load condition (WM load condition) load condition when compared to the standard condition, in which participants performed the primary task (i.e., creativity tasks) only. In contrast, because cognitive resource deprivation could activate more system 1 processes, on which the divergent thinking mainly relied, participants' performance on the divergent thinking test could be better facilitated in the WM load condition than in the standard condition. The working memory load therefore exhibited different impacts on the two kinds of creativity tasks.

METHOD

Subjects and Designs

Ninety-four undergraduate students (61 were women; *M* age = 20.3, *SD* = 1.7) from National Taiwan University

[2]Dominowski (1995) identified the features of insight problems as follows: (a) the solution of the problem is not beyond the knowledge of the problem solvers; (b) the initial attempt or hypothesis is usually strong but wrong, which creates obstacles to finding the solution; and (c) solving the problem requires change of problem representation or seeing the problem from a new perspective. The 2-4-6 problem is consistent with these properties.

participated in the experiment to earn course credit. The experiment had two between-group factors: working memory load manipulation (load vs. standard) and creativity task (insight-problem solving vs. divergent thinking). Fifty-four participants performed CVCTT; the other 40 participants performed the 2-4-6 task in which they were randomly assigned to either WM load or standard conditions, half in each. Genders were equally distributed.

Materials and Procedures

Working Memory Load Manipulation

Participants in the "WM load condition" were asked to repeatedly read aloud a series of consecutive integers from 1000 to 1005 ("one thousand and one, one thousand and two,...") with the rhythm of a metronome (one beat every 2 sec) while they were performing the creativity tasks assigned. There was no such requirement for participants in the standard condition, in which participants performed creativity tasks with the standard procedure described in the following.

Creativity Tasks

Divergent thinking test. The CVCTT (Wu, 1998) consisted of a verbal and a figural subtest. Participants were asked to write down as many as possible of the unusual uses of a pair of chopsticks in the verbal subtest and were asked to complete as many drawings as possible based on the figures of a Chinese character (see Figure 1) in the figural subtest. Each subtest was allowed 10 min.

Just as with the TTCT, the fluency, flexibility, and originality scores in the verbal subtest and the elaboration scores additionally in the figural subtest were scored[3] by two independent raters. The interrater reliabilities of each score were above .9. The standardized total scores (T scores) were also computed.

The 2-4-6 task. Participants performed the task in paper–pencil format. The general description and procedure of this task was as described earlier except participants were asked to proceed with 12 testing trials before the final correct answer was announced; they had to record the testing triple, the justification for this test, the Yes/No feedback, and their best current hypotheses on the answer sheets in each of the trials (for details, see Lien & Lin, 2011). A one-trial practice using three country names as the initial instance was used to ensure participants' understanding of the task procedure. Participants were allowed to finish the task at their own pace, which usually took no more than 35 min.

FIGURE 1 The figure of a Chinese character, "ren" (denoting human or people), in the figural subtest of the Chinese Version of Creative Thinking Test.

RESULTS

Indexes for the 2-4-6 Task

To calibrate the degree of creativity in hypothesis generation, the basic hypothesis structure that depicted participants' basic hypothesis space was created (the method of creating the structure, see Lien & Lin, 2011). A hierarchical structure identified four main categories of concepts (or conceptual branches) describing participants' hypotheses: (a) number category, such as natural numbers or integers; (b) number boundary, such as numbers below 100 or numbers above zero; (c) number difference, such as arithmetic series or difference by even numbers; and (e) number order, such as ascending numbers. Based on the basic hypothesis structure, participants' hypotheses could be categorized as either *new-perspective hypothesis* (revising the hypothesis with a new concept added from another conceptual branch, such as, from "evens" to "evens different by 2") or *same-perspective hypothesis* (revising the hypothesis within the same category, such as from "evens" to "integers"), in which the former type of hypothesis was considered more creative. The total number of hypotheses was the sum of the aforementioned two kinds of hypotheses plus implausible hypotheses, which referred to a hypothesis that was not consistent with existing evidence.

Results of Creative Performance upon WM Load Manipulation

As predicted, the accuracy rate of the 2-4-6 task for the WM load condition (20%) was significantly lower than that of the standard condition (50%), $\chi^2 = 3.96$, $p < .05$. Moreover, participants in the WM load condition generated fewer new-perspective hypotheses ($M = 2.85$, $SD = 1.14$) than did participants in the standard condition ($M = 3.65$, $SD = 0.88$), $t(38) = -2.49$, $p < .05$. Increasing the working memory load thus decreased the generation of creative hypotheses and hindered the performance of the 2-4-6 task.

[3]The fluency scores were simply the total number of responses generated by each participant. The flexibility scores represented the number of different categories of responses (e.g., the category of toys or decorations). The originality scores represented the sum of scores on each response, which was compared to the norm and scored as follows: responses appeared above 5% in the norm scored 0, responses appeared 2% to 4.99% in the norm scores 1, and responses appeared below 2% in the norm scored 2. The elaboration scores of the figural subtest were scored as the number of elaborated decorations in each response.

In addition, participants in the WM load condition generated fewer same-perspective hypotheses ($M = 3.30$, $SD = 2.3$) than participants in the standard condition ($M = 4.80$, $SD = 2.2$), $t(38) = -2.10$, $p < .05$. However, they generated more implausible hypotheses ($M = 1.0$, $SD = 1.7$) than the standard group ($M = 0.2$, $SD = 0.4$), $t(21.2) = 2.06$, $p < .05$. They did not differ in the total number of hypotheses (7.15 ± 3.1 vs. 8.65 ± 2.0, respectively, $t(31.9) = -1.82$, $p = .08$).

A reverse effect was found when comparing participants' performance between two experimental conditions in the divergent thinking test. Participants in the WM load condition performed better in many aspects of the divergent thinking test. As Table 1 showed, participants in the WM load condition obtained significantly higher fluency scores ($M = 17.04$, $SD = 4.40$) and marginally higher total scores ($M = 172.0$, $SD = 20.4$) on the verbal subtest than did participants in the standard condition (14.7 ± 3.81, and 162.1 ± 17.4, respectively), $t(52) = 2.08$, $p < .05$ for fluency score, and $t(52) = 2.01$, $p = .06$ for total scores on the verbal subtest. They also obtained significantly higher fluency, flexibility, and total scores on the figural subtest (14.93 ± 3.6, 10.15 ± 2.58, and 208.3 ± 4.4, respectively) than did participants in the standard condition (12.96 ± 3.7, 8.78 ± 2.4, and 195.2 ± 4.0, respectively), $t(52) = 1.97$, $p < .05$ for fluency, $t(52) = 2.04$, $p < .05$ for flexibility, and $t(52) = 2.19$, $p < .05$ for total score on the figural subtest.

To test the interaction between two factors (working memory load manipulation and creativity task), the number of new-perspective hypotheses in the 2-4-6 task as well as verbal and figural total scores in the divergent thinking test were used and transferred into normalized Z scores according to group mean of each task across the WM load condition and the standard condition.

TABLE 1
The Mean Scores and SDs of Divergent Thinking Test in "WM Load Condition" and "Standard Condition" in Experiment 1

	WM Load (n = 27)		*Standard (n = 27)*	
	M	*SD*	*M*	*SD*
Verbal subtest				
Fluency	17.04	4.40	14.70*	3.81
Flexibility	9.78	2.26	8.89	1.58
Originality	13.74	6.80	11.44	6.03
Total scores	172.00	20.38	162.07#	17.36
Figural subtest				
Fluency	14.93	3.60	12.96*	3.74
Flexibility	10.15	2.58	8.78*	2.36
Originality	13.96	5.43	11.33	5.16
Elaboration	4.70	4.06	4.04	2.78
Total scores	208.33	4.42	195.19*	4.04

*$p < .05$. #05 $< p < .1$.

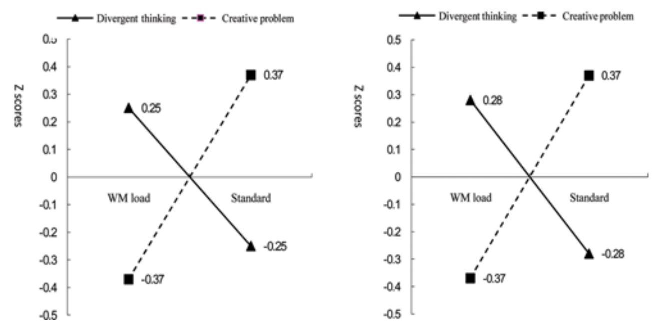

FIGURE 2 The Z scores of creativity measures on the 2-4-6 task and divergent thinking test in the WM load and the standard condition in Experiment 1 (A: verbal divergent thinking subtest, and B: figural divergent thinking subtest. (Figure is provided in color online.)

As Figure 2 shows, significant interaction effects were obtained. Working memory load manipulation had a different impact on idea generation of closed-ended from open-ended creative problem solving (for verbal subtest of divergent thinking, $F(1,90) = 9.01$, $p < .01$, and for figural subtest, $F(1,90) = 9.60$, $p < .01$).

DISCUSSION

The results of Experiment 1 showed that increasing the working memory load hindered participants' performance in closed-ended creative problem-solving. In addition to having lower accuracy rates, participants in the WM load condition also generated fewer hypotheses for both new- and same-perspective hypotheses but generated more implausible hypotheses; thus, the total number of hypotheses remained unchanged in the 2-4-6 task. These results indicated that mental resource deprivation lowered the quality but not the quantity of hypothesis generation. As predicted, mental resource, on which the exertion of system 2 relied, was important for generating novel as well as plausible hypotheses during the hypothesis-generation process. In contrast, increasing the working memory load facilitated participants' divergent-thinking performance. These results indicated that the idea generation involved in divergent thinking did not require cognitive resource and mainly relied on the effortless, associative process of system 1.

Some possible alternatives other than the dual-process account might be able to explain part of the results; however, none of them could explain the opposite impact of working memory load on different creative tasks. One of these alternatives is that the dual-task manipulation increases participants' motivation and causes them to concentrate on performing the task, by which the divergent-thinking performance benefits. However, this process cannot explain why the same manipulation did not lead to the same facilitating effect on the 2-4-6 task.

Similar to our findings, some researchers found improvement in divergent-thinking performance when a distracting environment existed—such as during dichotic listening (Dykes & McGhie, 1976; Rawlings, 1985) or in a rich and noisy environment (Ward, 1969). Previous researchers argued that distracting environments or tasks would widen participants' breadth of attention and lead to better-developed divergent-thinking abilities (e.g., Kasof, 1997). However, it is not evident why the same mechanism can hinder the quality of idea generation on 2-4-6 task performance, as found in this study.

EXPERIMENT 2

Experiment 2 adopted an individual difference approach to further investigate the relationship of working memory with different creativity tasks. In this experiment, each participant was asked to perform both creative measures and a task measuring working memory capacity. Divergent-thinking ability was measured through the verbal subtest of the CVCTT[4] (Wu, 1998), which was also used in Experiment 1. To generalize the findings, this study adopted different closed-ended creative problem-solving tasks and working memory capacity tests in Experiments 2A and 2B, respectively.

In addition to Wason's 2-4-6 task (Experiment 2A), a set of traditional insight problems was used to measure individuals' closed-ended creative problem-solving abilities in Experiment 2B. The relationship between performance in traditional insight problems and working memory capacity remained unclear; some studies did obtain a positive correlation between these factors (e.g., DeYoung et al., 2008; Fleck, 2008; Gilhooly & Murphy, 2005), whereas some others did not (e.g., Ash & Wiley, 2006). To further clarify this issue, five so-called pure insight problems were used in Experiment 2B. According to Weisberg's (1995) classification, a pure insight problem necessarily required a restructuring process rather than a hybrid or a noninsight one. Furthermore, a reading span task and an operational span task to measure the working memory capacity were adopted in Experiments 2A and 2B, respectively. Both types of measurement have been widely used and shown to have good reliability and could predict performance in complex cognitive tasks (for a review, see Conway et al., 2005).

As mentioned, individual differences in task performance due to working memory capacity could be observed only when the tasks involved system 2 according to the dual-process theory of cognition. With the hypothesis that solving open-ended creative problems required mainly system 1 but solving closed-ended ones additionally involved system 2, this study predicted that individuals' working memory capacity would significantly correlate to the 2-4-6 task and insight-problems performance but not to divergent thinking abilities.

EXPERIMENT 2A

Method

Subjects and General Procedures

Fifty-five undergraduate students (34 were women; M age = 20.3, SD = 1.2) from National Taiwan University participated in the experiment to earn course credit. Each participant proceeded with three tasks individually in 2 consecutive weeks; Wason's 2-4-6 task came first; the Chinese reading span test (Chen, 1998) with the verbal subtest of CVCTT (Wu, 1998) was presented in the second session—approximately 40 min in each participation.

Materials and Procedures

2-4-6 Task and the verbal subtest of CVCTT. The materials and procedures, as well as the scoring of the 2-4-6 task and the CVCTT, were the same as in Experiment 1.

Chinese reading span test (Chen, 1998). Participants were asked to memorize Chinese two-character terms (primary task) while reading sentences aloud. In each trial, participants were presented, on black computer screens, a series of Chinese sentences in white with the last two words printed in red, one sentence at a time. They were asked to read aloud each of the sentences and to memorize the two red words until the instruction appeared directing the participant to write down the memory items in order on the answer sheet. The trial size (i.e., number of terms to be recalled) continuously increased from two to six, and each level consisted of five trials. If participants could not accurately recall items on three of the five trials at any given level, the test ended.

The working memory capacity was scored as the participant's highest accurate level. For example, if a participant correctly memorized all items on more than three trials in level 3 but was able to memorize only up to one trial correctly in level 4, his/her capacity score was 3. When a participant could proceed onto level 4 with two trials correct, his/her capacity score was attributed 3.5 (Conway et al., 2005). The study included 150 sentences total, and participants usually finished the task within 25 min.

[4]Participants' scores on verbal and figural subtests of the CVCTT were highly correlated (Pearson's r ranged from .11 to .51) according to previous studies (Wu, 1998) and the results of Experiment 1. Therefore, Experiment 2 used only the verbal subtest for proper testing-time control.

Results

General Performance on Three Tasks

Participants' average working memory capacity was 3.48 ($SD = 0.93$), ranging from 2 to 6. For the 2-4-6 task, participants generated an average of 3.31 ($SD = 0.94$) new-perspective hypotheses (ranging from 1 to 5) during 12 trials. The successful ($n = 19$) and unsuccessful subjects ($n = 36$) significantly differed in the number of new-perspective hypotheses they generated (4.11 ± 0.74 vs. 2.89 ± 0.75, $t(53) = 5.77$, $p < .01$), but were not different in the number of "same-perspective hypotheses" or the total number of hypotheses, $t(53) = -1.24$, $p = .22$, and $t(53) = 0.69$, $p = .49$, respectively. These results replicated the findings of previous studies (Lien & Lin, 2011; Lin et al., 2005) that the number of new-perspective hypotheses as a creativity index was an effective predictor of final success in an insightful 2-4-6 task.

Participants' performance on the divergent thinking test was scored as follows: fluency ($M = 15.55$, $SD = 6.30$); flexibility ($M = 9.11$, $SD = 2.77$); originality ($M = 14.35$, $SD = 8.41$); and standardized total scores ($M = 168.4$, $SD = 28.5$). The scores in each category were significantly correlated with those of each of the others (the Pearson's r ranged from .65 to .84, $p < .01$). The interrater reliabilities of fluency, flexibility, and originality scores on the divergent thinking test were above .9.

The Relationships Among Three Measures

The correlations of the indexes on the previously discussed three tasks were computed. As Table 2 shows, participants' performance on the 2-4-6 task (using the number of new-perspective hypotheses and final success as measurement) correlated with their working memory capacity ($r = .27$, $p < .05$ for new-perspective hypothesis, and $r = .45$, $p < .01$ for final success). No indices of divergent thinking performance correlated with working memory capacity (the correlation coefficients ranged from $-.02$ to .06, $p = .67$ to .98). Furthermore, individuals' performance on divergent thinking and 2-4-6 task were not correlated (the correlation coefficients ranged from $-.02$ to $-.14$, $p = .32$ to .91).

Simultaneous-entry linear regression analyses were conducted using working memory capacity and one of the creative measurements as variables to predict the other creative measurements. The results demonstrated that working memory capacity contributed significantly to the generation of creative new-perspective hypotheses, with coefficient .27, $t(53) = 2.06$, $p < .05$, but the divergent thinking total score did not (with coefficient $-.13$, $t(53) = -.96$, $p = .34$). In contrast, neither the working memory capacity nor the number of new-perspective hypotheses could significantly predict participants' performance on the divergent thinking test (with coefficients .05 and $-.14$, $p = .73$ and .34).

Note that working memory resource deprivation in Experiment 1 improved participants' performance on the divergent thinking test, particularly on fluency scores; however, working memory capacity here could not predict participants' divergent thinking performance. Therefore, further analysis was conducted to observe the distributions of participants' divergent thinking performance on their working memory capacity. Participants were first separated by their fluency scores as either above ($n = 9$) or below ($n = 6$) 1 SD from average scores, as well as their working memory span as either above ($n = 11$) or below ($n = 10$) 1 SD from average scores. The results showed that one participant was separately categorized into WM-high/DT-high, WM-high/DT-low, and WM-low/DT-low groups; three participants were categorized into WM-low/DT-high groups.

TABLE 2
The Correlations for Variables on Three Tasks in Experiment 2A

	2-4-6 task		*Divergent thinking*			
	New-p	*Succ*	*V-flu*	*V-flex*	*V-orig*	*WM*
2-4-6 new-perspective	–					
2-4-6 success	62**	–				
Verbal fluency	−.09	−.07	–			
Verbal flexibility	−.09	−.02	.83**	–		
Verbal originality	−.14	−.13	.84**	.65**	–	
Working memory	.27*	.45**	−.02	.06	.00	–

Note. New-p = number of new-perspective hypotheses. Succ = final solution of 2-4-6 task (success or fail). V-flu = verbal fluency scores. V-flex = verbal flexibility scores. V-orig = verbal originality scores. WM = working memory capacity.

EXPERIMENT 2B

Method

Subjects and General Procedures

Sixty-eight undergraduate students (49 were women; M age = 20.1, $SD = 1.2$) from Fo Guang University participated in the experiment. Thirty-three of them participated in the experiment to earn course credit, and another 35 were recruited from advertisement and got paid for participation. The general procedures were the same as those of Experiment 2A, except that the 2-4-6 task was replaced with a set of pure insight problems. Moreover, the measurement of working memory was altered.

Materials and Procedures

Insight-problem task. The insight-problem task consisted of two parts: the matchstick arithmetic problem (adopted from Knoblich, Ohlsson, Haider, & Rhenius,

1999) and four other insight problems that required restructuring.

In each of the matchstick arithmetic problems, participants were presented with a wrong mathematical equation consisting of equal-size matchsticks arranged in Roman numerals (for an easy example, "VI = VII + I"). They were asked to move only one matchstick to correct the equation (e.g., "VII = VI + I"). There were five such problems; four of them were considered to be easy, and one was difficult. For the difficult one, such as "III = III + III," the correct move included the change of an operator yet the easy problem only involved the change of the number. Consider the previous problem; participants had to move the vertical matchstick on "+" horizontally to make a "=" sign, so that the equation became "III = III = III." This kind of problem involved the processes of constraint relaxation and chunk decomposition; therefore, the difficult problem was considered a pure insight problem (Knoblich et al., 1999).

Participants first performed an Arabic-Roman numerals matching practice for 5 min to familiarize themselves with the Roman numerals. They were then presented with four easy problems and one final, difficult problem. The presentation of easy problems allowed the participants to be more acquainted with the procedure as well as to create a mental set. Time limit was 3 min for each problem[5]. Participants usually finished the task within 25 min.

The other four pure insight problems were the trains-and-bird problem (Posner, 1973), the nine-dots problem (Dunker, 1945), the triangle problem (Schooler, Ohlsson, & Brooks, 1993), and the murder problem (Weisberg & DiCamillo, 1986). Participants were also given 3 min to solve each problem compatible with the matchstick arithmetic problem set. At the end of the test, participants were checked whether they were familiar with any of the problems (8 participants were familiar with one of the problems, 6 participants were familiar with two, and 1 participant was familiar with three of the problems). The participants usually finished the task within 15 min. The performance scores were calculated as percentage correct of unfamiliar problems. The contents and solutions for all the problems were presented in Appendix A.

Operational span task. Participants were instructed to memorize items (primary task) while performing a concurrent task involving mathematical operations (Turner & Engle, 1989). In each trial, participants were presented with a certain number of pairs consisting of a mathematical equation (e.g., $(8/2) + 2 = 6$) and a Chinese two-character item one by one on the computer screen. They were asked to answer aloud whether the equation was correct and memorize the verbal item that immediately appeared after the verification. The next pair of equation and verbal item was afterward presented. The same procedure was repeated until participants were asked to write all of the verbal items presented in that trial in order on an answer sheet. The trial size of memory items increased in increments of 1, from 2 to 7, with three trials at each level; 81 trials in total.

The test stopped if participants could not accurately remember all the verbal items on more than two trials at any given level when correct equation judgment was also required. The measurement of working memory capacity was scored as it was in Experiment 2A, except that a half point was given if a participant correctly completed only one trial at the highest level. Participants usually finished the task within 25 min.

The verbal subtest of CVCTT. The materials and procedures as well as the scoring method were the same as in the Experiment 2A.

Results

General Performance on Three Tasks

Working memory capacity. Participants' accuracy rate on the computation and judgment of mathematical equations was 91.6%. The average working memory capacity was 3.24 ($SD = 0.87$), which ranged from 1.5 to 7.

Insight problems. Participants' accuracy rates of the second, third, and fourth easy problems in the matchstick arithmetic problem set were 94.1%, 92.7%, and 95.6%, respectively (the first easy problem was used as a practice trial). The average accuracy rates of easy problems were significantly different from that of the difficult problem, 27.9%, $\chi^2 = 128.6$, $p < .01$. This difference was compatible with past findings (Knoblich et al., 1999) and revealed the difficulty of solving an insight problem. The accuracy rates of the trains-and-bird problem, the nine-dots problem, the triangle problem, and the murder problem were 7.35%, 35.29%, 14.71%, and 13.24%, respectively. Participants' averaged accuracy rate on the five insight problems was 16.8%, ranging from 0% to 66.7%.

Divergent-thinking ability. Participants' performance was scored as follows: fluency ($M = 14.35$, $SD = 6.11$); flexibility ($M = 8.44$, $SD = 2.78$); originality ($M = 11.56$, $SD = 8.19$); and standardized total scores ($M = 160.4$, $SD = 27.7$). These scores were significantly correlated (the Pearson's r ranged from .60 to .87, $p < .01$). The

[5]According to the findings of Knoblich and his colleagues (1999), 93% of solutions were generated in the first 3 min (although 5 min was allowed).

TABLE 3
The Correlations for Variables on Three Tasks in Experiment 2B

		Divergent Thinking			
	INS	*V-flu*	*V-flex*	*V-orig*	*WM*
Insight problem	–				
Verbal fluency	.02	–			
Verbal flexibility	.11	.80**	–		
Verbal originality	.05	.87**	.60**	–	
Working memory	.32**	.14	.19	.14	–

Note. INS = insight problem. V-flu = verbal fluency scores. V-flex = verbal flexibility scores. V-orig = verbal originality scores. WM = working memory capacity.

interrater reliabilities of fluency, flexibility, and originality scores on the divergent thinking test were above .9.

The Relationships Among Three Measures

The correlations of the indexes on the aforementioned three tasks were listed in Table 3. As in Experiment 2A, participants' working memory capacity was significantly correlated to their performance of insight-problem solving, $r = .32$, $p < .01$, but not to the indexes of divergent thinking test (the correlation coefficients ranged from .14 to .19, $p = .12$ to .25). Participants' performances on insight problems and the divergent thinking test were not correlated (the correlation coefficients ranged from .02 to .11, $p = .37$ to .90), either.

Also similar to Experiment 2A's findings, a simultaneous-entry linear regression analysis showed that working memory capacity contributed significantly to insight-problem performance, with coefficient .33, $t(65) = 2.70$, $p < .01$; however, the divergent thinking score did not (with coefficient .01, $t(65) = .07$, $p >= .94$). Neither working memory capacity nor insight-problem scores could significantly predict participants' performance on the divergent thinking test (with coefficients 1.70 and .01, $p = .20$ and .94).

The distributions of participants' divergent thinking performance on their working memory capacity were also analyzed here as in Experiment 2A. The results showed that two participants were categorized into WM-high/DT-high group, zero participant categorized into WM-high/DT-low group, three participants categorized into WM-low/DT-low groups, and two participants categorized into WM-low/DT-high groups.

DISCUSSION

The results of Experiments 2A and 2B, using different insight problem tasks as well as different working memory capacity tests, were in line with that of Experiment 1. Working memory capacity exhibited a positive correlation with and could effectively predict participants' generation of creative hypotheses in the 2-4-6 task and performance on pure insight-problem solving. On the contrary, it was not a requirement or a constraint of the performance on divergent thinking. In addition, individuals' performances on closed-ended creative problem solving and on open-ended divergent thinking were not correlated. These results supported our claim that the open-ended versus closed-ended creative problem-solving tasks exhibited different involvement of the two systems.

Although individuals' working memory capacity and their divergent thinking performance were not correlated, the distribution analyses in Experiment 2A and 2B showed some participants (3 and 2 participants, respectively) who had very low working memory capacity performed very well in divergent thinking test. These results indicated a possibility that some individuals might naturally prefer system 1 processing mode (hence performed better on divergent thinking test) due to their working memory capacity constraint,[6] compatible with the claim of dual-process theorists (e.g., Stanovich, 1999). However, when the working memory resources were severely deprived, as the manipulation in Experiment 1, most individuals could process information only in system 1 mode and hence their divergent thinking performances were improved.

GENERAL DISCUSSION

This study examined how working memory played different roles in open-ended versus closed-ended creative problem solving, in particular, divergent thinking and insight problem solving, which were applied widely but independently in the creativity research literature. Under the framework of dual-process theories (e.g., Evans, 2003, 2007; Sloman, 1996; Stanovich & West, 2000), the different task demands of divergent thinking and insight problem solving might exhibit different involvement of the two systems and therefore different relationships with working memory. It was hypothesized that producing ideas without many constrains in divergent thinking relied more on associative, effortless system 1 processing. On the other hand, generating novel but plausible solutions for attending a solving goal in insight problem solving required both system 1 and rule-based,

[6]The hypothesis that individuals with low working memory capacity preferred system 1 processing did not imply that others who possessed higher working memory capacity preferred system 2 processing. Our data showed that individuals' working memory capacity did not correlate with their divergent thinking performance; it is possible that individuals with higher capacity could choose either system 1 or 2 processing mode.

resource-limited system 2 processing, and hence was constrained by working memory resources.

Experiment 1 used a dual-task design, which lowered the available mental resources, and showed that this manipulation hindered the generation of creative hypotheses in the insightful 2-4-6 task but aversely improved participants' divergent-thinking performance. Experiments 2A and 2B adopted the individual difference approach and generalized insight problems as well as working memory capacity tests, and showed that only insight problem-solving performance correlated to individuals' working memory capacity, whereas divergent thinking performance did not. These results were consistent with the predictions of the dual-process account and supported Perkins' (1998), but not to Campbell's conceptions (1960), that the idea generation in creative problem solving was not as random or divergent.

The findings of this study might offer a possible explanation for some inconsistencies found in the creativity research literature (e.g., when investigating the relationships between emotions, intelligence with creativity as noted earlier). As working memory capacity could be decreased when people were in a negative mood, such as depression (e.g., Arnett et al., 1999), the performance on insight problem solving that was constrained by working memory resources was found hindered in a negative mood situation (e.g., Isen, et al., 1987) whereas divergent thinking performance was not (e.g., Adamen & Blaney, 1996). Furthermore, working memory is an essential construct to traditional intelligence tests (e.g., Shelton, Elliott, Matthews, Hill, & Gouvier, 2010). It is reasonable that intelligence stably correlated with closed-ended creative problem-solving performance whereas divergent-thinking performance required only a certain level of intelligence (e.g., Sternberg et al., 2005). The research findings in the creativity literature should carefully separate different tasks when considering the relationship of various factors with creativity.

The distinction between measures on individuals' creative potentials in this study might be extended to reflect the difference between artistic and scientific creativity. Generally speaking, scientists mostly discover principles of the world according to phenomena and evidence whereas many artists create art works without constraining the work to concrete explanations of objectives—at least for certain arts, such as painting (e.g., Stent, 2001). Closed-ended creative problem solving (in particular, the 2-4-6 task) more closely resembled the scientific discovery processes, although in a simplified way (e.g., Nickerson, 1999; Vartanian et al., 2003); divergent-thinking tasks characterize more artistic processes because the artists were found to be more likely to reach the highest level in a divergent thinking test than scientists (e.g., Smith, Carlsson, & Sandstrom, 1985). This implication shed light on the recent debate of how blind an innovative artwork, as exemplified by Picasso's production of *Guernica*, was created (cf. Simonton, 2007; Weisberg & Hass, 2007). Given its open-ended nature, artistic creativity might require more divergent thinking than scientific creativity (see also Simonton, 2005). The extent that artistic and scientific creativity involve system 1 or system 2 processing, and how they affect working memory, are worthy of further investigation. In addition, if factors are found to be correlated differently with divergent thinking and creative problem-solving, they might be used to design for different training programs and be applied to improve creative achievements.

Still, other relevant issues are worth being further clarified. For example, given solving an insight problem required both system 1 and system 2 processing, what is the mechanism of the shift between processing modes? Stanovich and West (2000) proposed that the switch of system 2 to system 1 processing was possibly due to less inhibition imposed by system 2 on system 1. Gabora (2010), as noted earlier, explained it in a neurology level by introducing the recruit of *neurds*, which responded to abstract and atypical microfeatures of the problem, in the memory system. Vandervert and colleagues (2007) identified the role of cerebellum on unconscious processing and predictions to give input to the conscious working memory execution. This is clearly an unsolved, but important, issue.

Whether individuals who are good at divergent thinking or insight problem solving show differences in the use of heuristics or analytic strategies on other reasoning tasks is another interesting issue that remains for further investigation.

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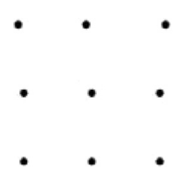
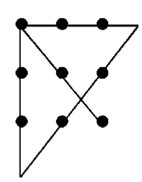
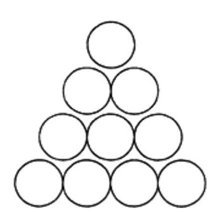
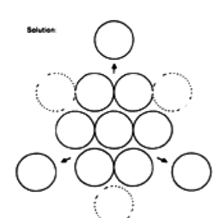
Appendix A

Insight problems (in bold with number labels) and solutions used in Experiment 2

The matchstick arithmetic problem

	problems	*Solutions*
easy	VI = VII + I	VII = VI + I
	IV = III + III	VI = III + III
	II = III + I	III = II + I
	IX = VIII + III	XI = VIII + III
difficult	**(1) III = III + III**	**III = III = III**
Four other insight problems		
(2) Trains and bird problem		80 km (100/(60 + 40))*80 = 80)
Two trains 100 km apart start toward each other at 60 km/hr and 40 km/hr, respectively. As the trains start, a birdflies from the front of one train towards the second. On reaching the secondtrain, the bird turns round and flies back to the first train, and so on, until thetrains meet. If the bird flies at 80 km/hr, how much distance will the bird haveflown before the trains meet?		
(3) Nine dots problem		
Connect nine dots in a squarearray by drawing four straight lines.		
(4) Triangle problem		
Given a diagram of circles arranged in a triangle shape withone in the top row then two, three, and four, respectively, in the lower rows, how can youmove three circles to make the triangle point the other way?		
(5) Murder problem		Charlie is a gold fish and Tom is a cat.
Dan came home and found Charlie dead on the floor and Tom in the same room. On the floor, Dan saw some broken glass and water. How did Charlie die?		