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BRIEF REPORT

Effects of subliminal hints on insight problem solving

Masasi Hattori · Steven A. Sloman · Ryo Orita

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Abstract Two experiments tested a total of 509 participants on insight problems (the radiation problem and the nine-dot problem). Half of the participants were first exposed to a 1-min movie that included a subliminal hint. The hint raised the solution rate of people who did not recognize it. In addition, the way they solved the problem was affected by the hint. In Experiment 3, a novel technique was introduced to address some methodological concerns raised by Experiments 1 and 2. A total of 80 participants solved the 10-coin problem, and half of them were exposed to a subliminal hint. The hint facilitated solving the problem, and it shortened the solution time. Some implications of subliminal priming for research on and theorizing about insight problem solving are discussed.

Keywords Subliminal priming · Implicit cognition · Convergence problem · Nine-dot problem · Ten-coin problem

A striking aspect of insight problem solving occurs when people reach an impasse despite having all the knowledge required for a solution. To explain how people resolve impasses, some theorists emphasize changes in heuristic search of the problem space (e.g., Chronicle, MacGregor, & Ormerod 2004; Kaplan & Simon, 1990), while others emphasize changes in the distribution of activation in memory (e.g., Ohlsson, 2011; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). The former view puts the theoretical workload on controlled, attention-demanding, and conscious processes, the latter view on automatic, effortless, and unconscious processes such as the spread of activation.

Gick and Holyoak (1980) long ago demonstrated the importance of awareness in accessing relevant information. They used Duncker's (1945) *radiation problem*, which requires devising a method to destroy an inoperable tumor in a patient's stomach by a kind of ray without causing any serious damage to surrounding healthy tissue. Presenting a story that was structurally analogous to the solution (i.e., to converge multiple low-intensity rays) did not enhance participants' success unless it was explicitly presented as a hint. Lockhart, Lamon, and Gick (1988) claimed that conceptual processing of the prime triggers an awareness of the relevance of the information and is required for transfer. On the other hand, Maier (1931) observed that people can make use of a hint incidentally given to them to solve the two-string (pendulum) problem even if they were not aware of the hint. Schunn and Dunbar (1996) also showed that people can transfer their knowledge analogically to help solve even a complex problem without awareness that they are doing so.

We examine the contribution of hints that are primed subliminally to solving insight problems. Like Maier's (1931), most problem-solving studies have been concerned with transfer from analogical tasks, or *supra*liminal priming, in which an individual is fully aware of the stimulus, although he or she may not be aware that it is actually a hint. This method, however, may be susceptible to both memory failures (e.g., participants may merely have forgotten being aware) and demand characteristics (Bowden, 1997). Subliminal priming has neither disadvantage and, thus, offers an ideal method for examining the role of awareness in the resolution of impasses. To our knowledge, however,

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M. Hattori (✉)
Department of Psychology, Ritsumeikan University,
56-1 Toji-in Kitamachi, Kita-ku,
Kyoto 603-8577, Japan
e-mail: hat@lt.ritsumei.ac.jp

S. A. Sloman
Department of Cognitive, Linguistic, and Psychological Sciences,
Brown University, Providence, RI, USA

R. Orita
Department of Psychology, Ritsumeikan University, Kyoto, Japan

this technique has not been applied to insight problem solving, except by Nishimura and Suzuki (2006), who report, without describing their methods in detail, subliminal priming of the solution time for the T Puzzle.[1]

Evidence does suggest that subliminal priming affects people's preferences (Kunst-Wilson & Zajonc, 1980), interpersonal judgments (Bargh & Pietromonaco, 1982), brand choice (Karremans, Stroebe, & Claus, 2006), motivation in classrooms (Radel, Sarrazin, Legrain, & Gobancé, 2009), and even higher-order goals (Légal, Chappé, Coiffard, & Villard-Forest, 2012). There is, however, not yet agreement on the definition of a perceptual threshold (Snodgrass, Bernat, & Shevrin, 2004), and some researchers still dismiss subliminal perception (see Holender, 1986). Most studies define subliminal perception in terms of subjective report. In this study, we use a more conservative method to test awareness, forced choice recognition between the true prime and similar distractors.

In Experiments 1 and 2, the effect of subliminal priming on insight problem solving was examined using a short movie that included a hint that participants were not aware they had seen. In Experiment 3, a new method was used to address concerns about the methodology of Experiments 1 and 2.

Experiment 1

In the first experiment, we examined whether subliminal priming can affect human insight problem solving using the radiation problem. Half of participants were given an unrecognized hint during the attempt to solve the problem.

Method

Participants and design

A total of 206 undergraduate students (89 female and 117 male; age: 19–24 years, M = 20.1, SD = 1.1) from Ritsumeikan University and Ryukoku University were tested. They were randomly assigned to either a hint or a no-hint condition.

Materials and apparatus

The hint stimulus was presented as part of a 56-s movie, composed from one hint image (exposed 33 ms × 60 times), two mask images, three filler images, and one fixation image (Fig. 1; see the online materials for more detail). The movie was projected on a screen at the front of the room by a liquid crystal display projector. *The radiation problem* was then presented in a booklet along with diagrams (available online). In the *recognition task*, participants were presented four figures (see Fig. 2), and their task was to choose the one that they thought had been shown with a confidence rating— "*sure*," "*half-sure*," and "*guess*".

Procedure

The experiment was administered in Japanese to groups in two different classrooms. Two minutes after participants started to solve the problem, they were asked to engage in an "irrelevant" task for 1 min. While participants in the hint condition watched the hint movie (described as "an irrelevant short movie") on the screen, participants in the no-hint condition tackled the dummy calculation task (e.g., 23+18 =) to try to solve as many problems as possible while not looking at the screen. They were given a total of 9 min to complete the problem, including the initial 2-min trial period, the 1-min exposure or calculation period, and the second 6-min trial period. Finally, they were asked whether they have seen the radiation problem before and chose an answer among the options "yes," "no," and "I am not sure, but I might have seen it before."

Results and discussion

Of the 206 participants, 10 reported that they had seen the radiation problem before, 9 in the hint condition correctly identified the hint image with certainty, and 2 in the no-hint condition reported that they mistakenly had a glance at the hint movie. Data from all these participants were excluded from analysis. Of the remaining 185 participants, 56 % (49/88) solved the problem in the hint condition, whereas only 37 % (36/97) succeeded in the no-hint condition, $\chi^2(1, N = 185) = 6.41$, $p = .01$, $\phi = .19$.

In the recognition task, 55 % (48/88) selected the correct hint image (2 out of 88 did not answer) significantly more than chance (i.e., 25 %), $p < 10^{-8}$, but the majority (69 % = 33/48) of them reported that it was a "guess," while the others reported "half-sure." This means either that some of participants *saw* the hint with some degree of awareness or that they were biased to select the hint image. We did verify in pilot experiments that most people failed to recognize the hint. But if they saw it, correct responders in the recognition task should show a higher solution rate than incorrect responders. They did not. Solution rates for the two subgroups of the hint group were very close, 58 % (28/48) versus 55 % (21/38), $\chi^2(1, N = 86) = 0.082$, $p = .78$, $\phi = .03$. This suggests that correct identifiers did not have the hint image available to awareness

[1] Bowden (1997) revealed the effect of subliminal priming on anagrams. Anagrams, however, are not insight problems according to Weisberg's (1995) taxonomy, because solving an anagram does not require changes in the problem representation.

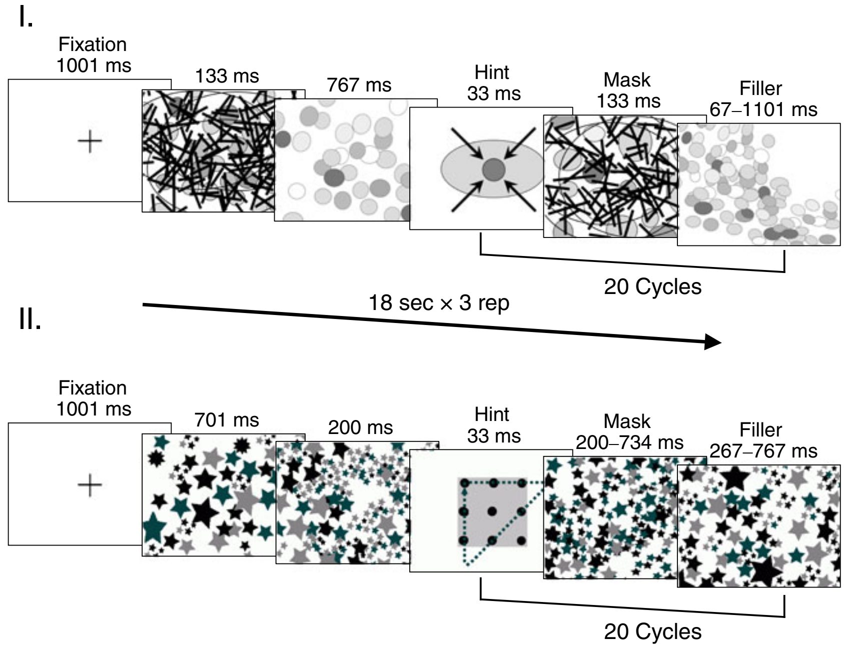


Fig. 1 Schematic description of a sequence of frames including implicit hint stimulus presented in Experiments 1 (I) and 2 (II). These sequences (18 s long each) are looped three times with a 1-s blank between each loop and formed a total of a 56-s long movie that included 60 hint cuts

but, instead, were biased to choose it for some other reason. Perhaps it simply looked more plausible than the other images.[2] In the next experiment, designed to examine the facilitation effect in a different problem, we examine this issue directly.

Experiment 2

In Experiment 1, an unrecognized hint raised the solution rate of the radiation problem by 50 %, suggesting that subliminal priming helped to solve an insight problem. In this experiment, we tried to replicate the results using a different problem that was less text based and more purely spatial, the nine-dot problem.

Method

Participants and design

A total of 133 undergraduate students from Brown University participated in the experiment. They were randomly assigned to either a hint or a no-hint condition. Of these, 4 did not follow the instructions correctly, and their data were excluded. The remaining 129 participants consisted of 59 female, 65 male, and 5 unknown (age range: 17–53 years, $M = 20.1$, $SD = 3.2$).

[2] Unfortunately, we did not collect data on the recognition task from the no-hint group. Such data would have revealed whether there are biases in favor of one of the response options.

Materials and apparatus

A hint movie for the nine-dot problem and an answer booklet were used as in Experiment 1 (Fig. 1; see the online materials for details). The nine-dot problem was followed by a *recognition inquiry* (only for the hint condition), where participants were asked whether they saw the hint and they chose an answer from "yes," "no," and "I thought I saw something, but I didn't recognize it clearly." In the *recognition task*, they were given a forced choice among four figures—the true hint image and the identical image rotated by 90°, 180°, and 270°.

Procedure

The experiment was administered to two groups in different classrooms, and the procedure was similar to Experiment 1. One minute after the experiment started, participants were shown the hint movie or given the dummy calculation task. They were given a total of 5 min to solve the problem.

Results

Of the 129 participants, 55 reported that they had seen the nine-dot problem before, and 3 finished the task successfully within 1 min (i.e., before the exposure period). All their data were excluded from further analysis, unless otherwise stated. Of the remaining 71 participants, 2 out of the 28 participants tested in the hint condition reported having recognized the hint, but they all failed to correctly identify the true hint image. Solution rates in the hint and no-hint conditions were 29 % (8/28) and 9 % (4/43), respectively, $p = .05$ (Fisher's exact test), $\phi = .25$ (see Fig. 3). This result can be compared with an effect of a similar

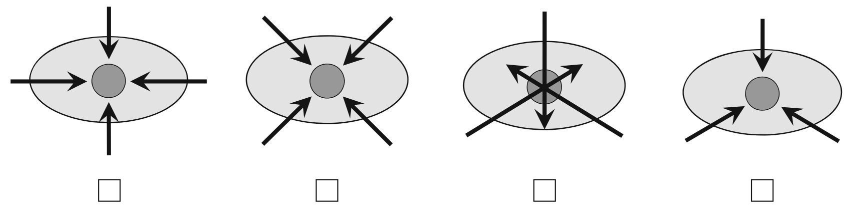


Fig. 2 Four alternatives prepared for the recognition task in Experiment 1. Participants forcedly chose one that they thought had been shown

*supra*liminal hint reported by Chronicle, Ormerod, and MacGregor (2001), who used a shading pattern overlaid on the array of nine dots as a hint without mentioning its relevance. Their solution rate was 16 % (5/31), a similar effect size, ϕ = .29.[3]

If the hint facilitates solving the problem, solutions should be similar to the one suggested by the hint. Figure 3 also shows the proportion of solutions that had the same structure as the hint, as opposed to one of the other three solutions (see Fig. 4). Of the successful solvers in the hint condition, 88 % (7/8) matched the hint, whereas only 25 % (1/4) of successful solvers did so in the no-hint condition, exactly what would be expected by chance. The difference between the two conditions was marginally significant, p = .07 (Fisher's exact test), although the effect size was large ϕ = .63.

Results regarding participants' awareness were dissociated from the effect of the hint. Only 5 out of 57 participants (including the 27 who knew the problem and the 2 who finished within 1 min) in the hint condition reported that they had recognized the hint, but 3 of the 5 failed to correctly identify the target in the recognition task. The distribution of their choices in the recognition task also indicated that they did not explicitly recognize the hint. The frequency of choosing each solution (Fig. 4) was 17, 13, 14, and 9, respectively (4 chose nothing), no different than a uniform distribution, $\chi^2(3, N = 53) = 2.47$, p = .48. Recognition confidence also failed to predict the ability to solve the problem. The proportions correct were 40 % (2/5), 22 % (2/9), and 30 % (13/43) for participants who reported "yes," "unsure," and "no" to the recognition inquiry, respectively, p = .79 (Fisher's exact test), Cramer's V = .09 (a very small effect size).

Discussion

The hint tripled the solution rate. Together with the results of Experiment 1, the results in the hint condition (i.e., a high solution rate, a high likelihood of solving the problem in a way consistent with the hint, and a low recognition rate) suggest an effect of subliminal stimulation. The method of Experiments 1 and 2 may raise some concerns, however. First, the effects might be caused by the mask or filler image instead of the hint. Second, insight might have been hampered by the calculation task in the control conditions. These interpretations actually are not consistent with the finding that solutions matched the hint in the hint condition. Additionally, the latter interpretation is rendered suspect by the higher solution rates in the no-hint conditions (i.e., 37 % and 9 %), as compared with the typical solution rates in the literature (9 % and 4 %, respectively).[4] However, we do not have direct evidence that the explicit images and the calculation task were irrelevant to the facilitation effect. Third, it might be regarded as a problem that all the participants did not receive exactly the same hint stimulus. That is, because the experiment was administered to participants as a group, the distance and angle to the hint varied with their seating positions. All of these concerns were addressed in the next experiment.

Experiment 3

In this experiment, the subliminal priming effect was examined by a more strictly controlled method than in the previous experiments. In order to generalize the results, we used a different insight problem than for previous experiments, the 10-coin problem. The problem is to turn a triangle composed of 10 coins upside down by moving no more than 3 coins (see Fig. 5).

Method

Participants and design

A total of 80 adults (39 female and 41 male; age: 18–25 years including 1 unknown, M = 21.2, SD = 1.6) were tested. They were randomly assigned to either a hint or a no-hint condition.[5]

[3] Since they actually did not include a control condition, we used a solution rate of the control group, 0% (0/27), reported in MacGregor, Ormerod, and Chronicle (2001).

[4] The radiation problem is based on data from a total of 250 participants from 10 control conditions reported in Gick and Holyoak (1980), Spencer and Weisberg (1986), Holyoak and Koh (1987), and Thomas and Lleras (2007, 2009). The nine-dot problem is based on data from a total of 284 participants from seven control groups (or eliminated data) reported in Burnham and Davis (1969), Weisberg and Alba (1981), MacGregor et al. (2001), and Kershaw and Ohlsson (2004).

[5] Participants actually were assigned to one of four conditions: 2 (hint vs. no hint) × 2 (instruction vs. no instruction). In the instruction conditions, they were encouraged to generate novel ideas. A directive like "Think unconventionally" was displayed on the center of the screen for 1 s immediately after each prime (Fig. 5). No message was displayed in the no-instruction condition. There was no main effect of the instruction, $\chi^2(1) = 0.15$, p = .71, nor an interaction with the hint, $\chi^2(1) = 0.15$, p = .71, by a two-way ANOVA based on a chi-square distribution. We therefore refrain from further discussion of this variable.

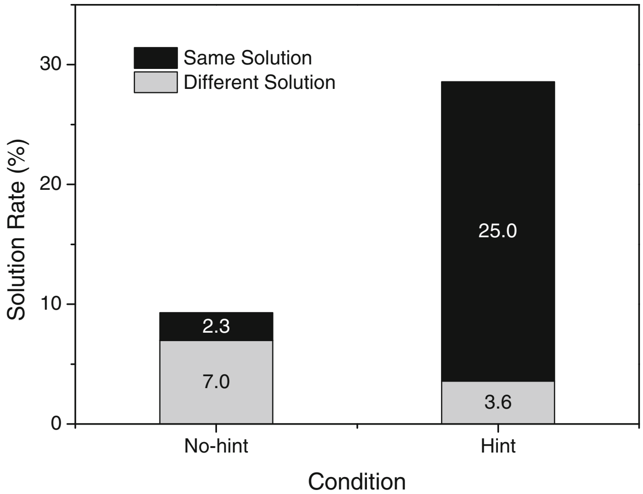


Fig. 3 Percentage of participants who solved the nine-dot problem in Experiment 2

Materials and apparatus

Participants solved the 10-coin problem on a 10.1-in. tablet computer (NEC PC-LT550FS) using a touch pen. All the operations, including receiving the hint and answering post-questions, were carried out on the device.

Procedure

The experiment was administered in Japanese individually. Participants were able to move any coins on the screen or to return to the initial state whenever they desired. In the hint condition, the hint was periodically displayed on the screen as the problem was solved (Fig. 5). In the no-hint condition, the hint was replaced by a blank screen. Before they started, participants read general instructions on the screen. They were notified in advance that they would see irregular polygons (i.e., a pattern mask) every 10 s and were falsely instructed that the experiment aimed to examine the effect of "irrelevant" visual stimuli during problem solving. The task ended when they successfully solved the problem. After they solved the problem or 4 min had passed, they were given several questions identical to those in Experiment 2 (see the online materials).

Results and discussion

Of the 80 participants, 3 reported that they had seen the 10-coin problem before, and 1 in the hint condition reported having recognized the hint. All their data were excluded from further analysis.

The solution rate was 26 % (10/38) in the hint condition, but only 5 % (2/38) in the no-hint condition, $\chi^2(1, N = 76) = 6.33$, $p = .012$, $\phi = .29$. Figure 6 shows the cumulative distribution of successful solvers as time elapsed in each group. A log-rank test for equality of rise curves (i.e., survivor functions) showed a significant difference of solution times between the two groups, $\chi^2(1, N = 76) = 6.3$, $p = .01$, $\phi = .29$. In the recognition task (25 % chance level), only 26 % (10/38) selected the correct answer, $p = .85$ (binomial test).

In sum, the effect of Experiments 1 and 2 was replicated. The hint quintupled the solution rate and shortened the solution time. The results suggest that the main cause of facilitation in the previous experiments was not explicit images given as masks or inexperience with the calculation task but the hint itself.

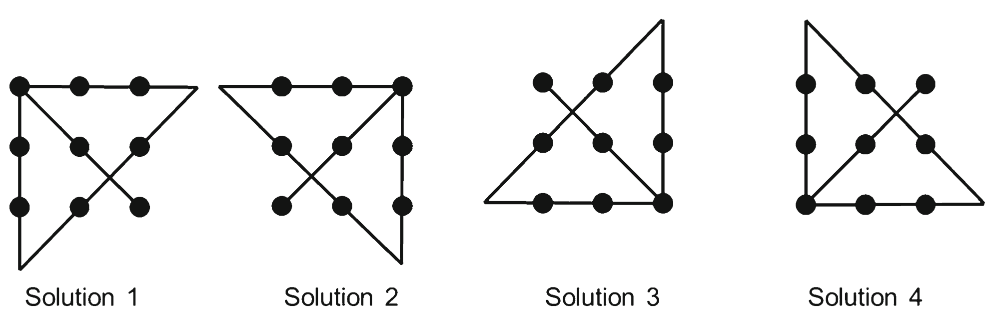
General discussion

In three experiments, we observed facilitation from subliminal priming on insight problem solving. Hints increased solution rates in all three experiments, despite participants being both subjectively unaware of primes and also unable to confidently discriminate the target from distractors.

The results shed light on how impasses are resolved. The subliminal priming effect is more consistent with theories based on activation in memory, including the *redistribution theory* of insight (Ohlsson, 2011), than with those based on awareness. Exposure to a hint can activate insightful ideas without awareness, increasing the probability of producing a corresponding strategy and of deactivating inappropriate ones to escape from the impasse.

One condition likely critical to the effect of subliminal priming is *preparedness*. Moss, Kotovsky, and Cagan (2007) obtained evidence that *open goals* set in a task (i.e.,

Fig. 4 Four solutions of the nine-dot problem. Only solution 1 matches to the implicit hint



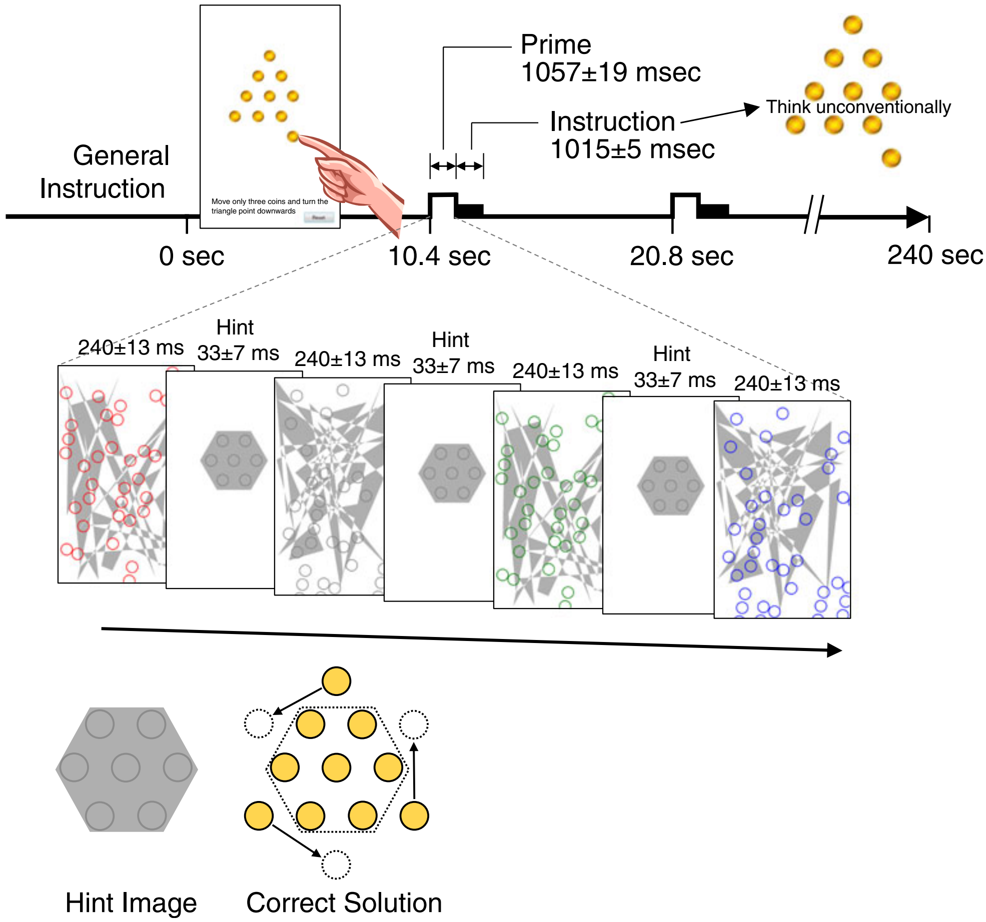


Fig. 5 Schematic depiction of the temporal task structure in Experiment 3. Actual duration time of each image was measured by counting the number of frames (600 fps) captured by a high-speed camera (Casio EX-F1). The means and standard deviations of values obtained by 10 measurements are shown (*M* ± *SD*). In the no-hint condition, each hint image was replaced by a blank screen (23±6 ms each)

unsolved problems) promoted acquisition of hints implicitly presented in another task. The *opportunistic assimilation hypothesis* (Seifert et al., 1995) supposes that reaching impasse sets up "failure indices" in memory and relevant information later introduced in the environment may lead to retrieval of these indices, which may result in an insight.

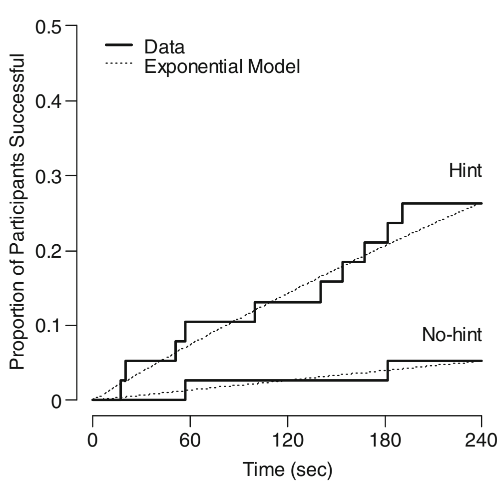


Fig. 6 Proportion of participants who successfully solved the 10-coin problem, with time in each condition

So the procedure we used in Experiments 1 and 2 (i.e., presenting the hint a few minutes after participants started tackling the problem) might have made participants receptive to priming. Waiting a few minutes allowed them to set their goals. Indeed, the effectiveness of incubation periods in creative thinking could involve such goal setting.

Psychologists have argued about whether insights are initially unconscious or not. Some theorists have claimed that "insights are not always conscious from the start" (Siegler, 2000, p. 82) or that first, "unconscious thought 'boosts' the associative search for creative solutions" and then "solutions are transferred to consciousness" (Zhong, Dijksterhuis, & Galinsky, 2008, p. 916). Such claims are consistent with our present data, but such processes may require enabling conditions and the absence of disablers. Conscious verbal processes can interfere with unconscious processes in insight problem solving (Schooler, Ohlsson, & Brooks, 1993). Moreover, although conscious control alone is known to facilitate creativity (e.g., Nickerson, 1999), intentional activities can hamper unconscious processes. Mindful students in a classroom were insensitive to subliminal priming (Radel et al., 2009), and similarly, conscious attention eliminated priming effects on social perception (Dijksterhuis & Van Knippenberg, 2000). How priming effects or unconscious processes interact with more intentional and controlled activities is an important open issue. Unconscious processing in insight problem solving cannot be studied by methods like verbal self-report that require conscious processing. Thus, we must rely on experimental methods that tap implicit processes, like the subliminal priming technique.

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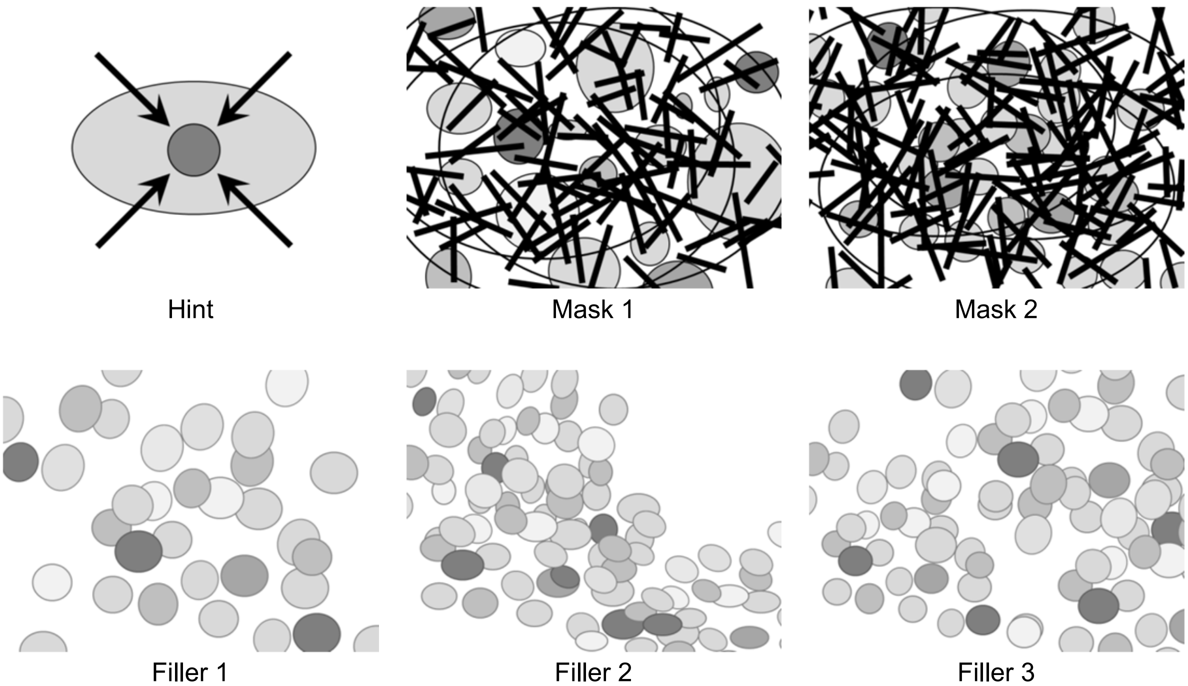
Experiment 1 Materials

Implicit Hint Movie

The hint stimulus was presented as part of a 56-second long MPEG-2 movie (NTSC, frame size: 720 × 480 pixels, frame rate: 29.97 fps; available online). The movie was composed from one hint image, two mask images, three filler images, and one fixation image. The mask images were constructed using similar fragments of the hint image, whereas the filler images were neutral in this regard. The movie consisted of a single sequence of frames looped three times to construct a movie of a sufficient running time interpolating a one-second interval (black screen) between each loop. Each loop consisted of 510 frames (18 sec) including 20 separate hint frames (a total of 60 separate hint images in a 56-sec movie). The loop started with a fixation mark at the center of the screen followed by a mask and filler images, and 20 cycles of a set of hint, mask, and filler images as detailed in Figure 1. The movie was projected on a screen at the front of the room by a liquid crystal display projector.



Answer Booklet

The radiation problem was then presented in a booklet with instructions identical to those of Gick and Holyoak (1980) along with diagrams as follows. For the no-hint group, the booklet also included 40 filler addition problems (e.g., 23 + 18 =______) and, for the hint group, a recognition task followed by a familiarity inquiry, as well as general procedural instructions. In the recognition task, participants were presented four figures (Figure 2 in the text) and their task was to choose the one that they thought had been shown. They also answered a confidence rating—"sure," "half-sure," and "guess"—for the one they chose. The familiarity inquiry asked whether they have seen the radiation problem before. They chose an answer among the options "yes," "no," and "I am not sure, but I might have seen it before."

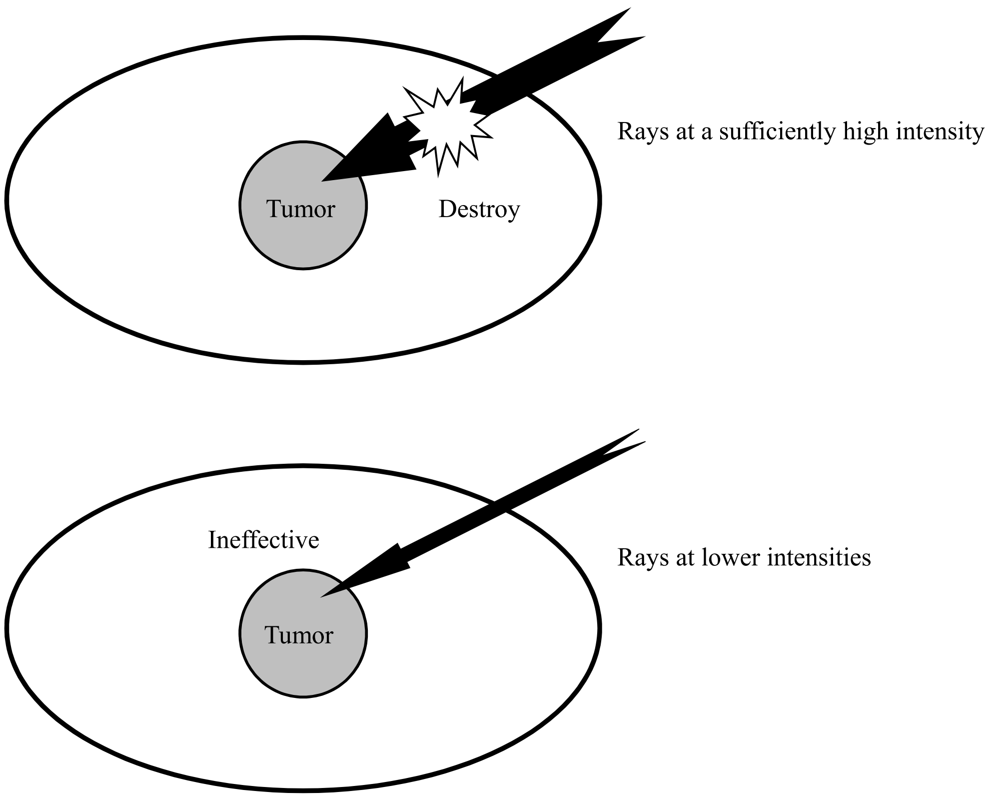
INSTRUCTIONS

Please do not open this booklet until you are given a signal to begin. You should flip every page as instructed. Do not go back to previous pages. Read the following instructions carefully, and if you have any questions, please do not hesitate to ask.

This is an experiment on human thinking. The purpose of this experiment is to examine the effect of diversion on thinking. It is often said that good ideas come after we have a break. You are asked to solve a simple problem described later. One minute after you start to solve the problem, you are to engage in an irrelevant task for one minute. There actually are two conditions: The Winding-Up Condition and Relax Condition. In the Winding-Up Condition, you are supposed to accurately solve as many as possible calculation problems for one minute. In the Relax Condition, you are asked to watch an irrelevant short movie on the screen three times over the course of one minute. Note that people in the Winding-Up Condition are asked to concentrate on the task and should not glance at the screen. Similarly, people in the Relax Condition should keep the screen in sight for the full minute. After this period of time, you will return to the initial problem. If you solve the problem before the time period elapses, please wait quietly.

Your condition is WINDING-UP / RELAX.

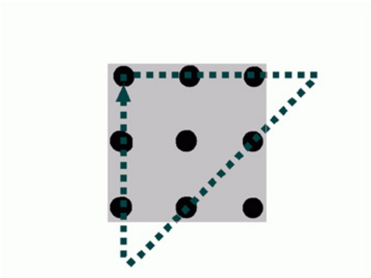
Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?



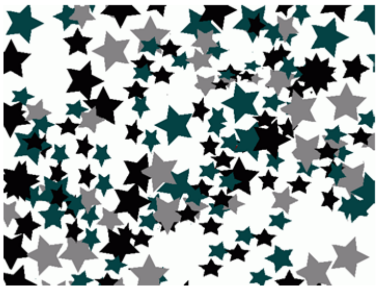
Experiment 2 Materials

Implicit Hint Movie

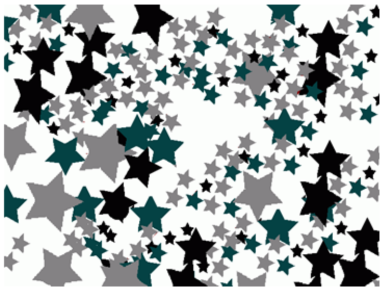
The hint movie was also similar to that used in Experiment 1 except the content images (shown below). The mask and filler images were constructed using similar pieces of figures. The only difference between the mask and filler images used in this experiment was that small pieces of figures were densely placed in the mask image around the place where the diagonal line of the hint image was located.



Hint



Mask 1



Mask 2

Filler 1

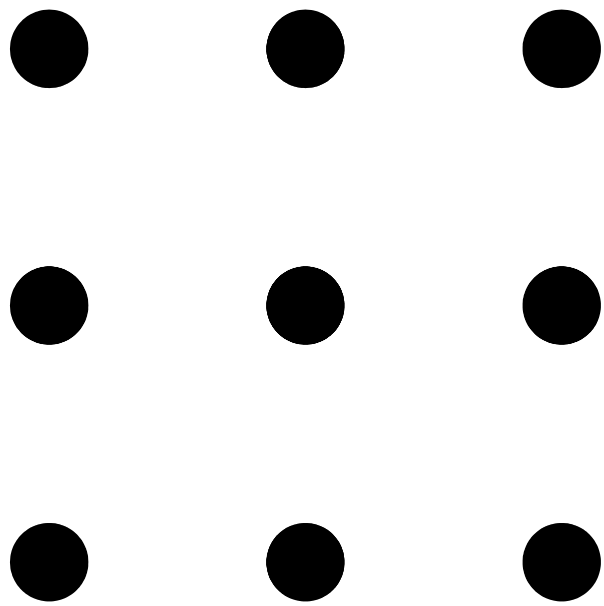
Filler 2

Filler 3

Answer Booklet

The nine-dot problem was presented in the answer booklet with an array of 3 × 3 dots as shown below. A recognition inquiry (only for the hint condition) was introduced before the recognition task to test awareness of the hint directly. In this task, participants were asked whether they saw the hint and they chose an answer from "yes," "no," and "I thought I saw something, but I didn't recognize it clearly." They were also given a forced choice among four figures—the true hint image and its 90, 180, and 270 degree rotated ones as shown below.

Your task is to draw four lines which, between them, go through all nine dots below. However, you must abide by the following constraints: the lines must be straight; the lines must be connected (i.e., once you have started drawing you must not lift your pen off the page); you must not retrace over a line you have already drawn.



RECOGNITION INQUIRY AND RECOGNITION TASK

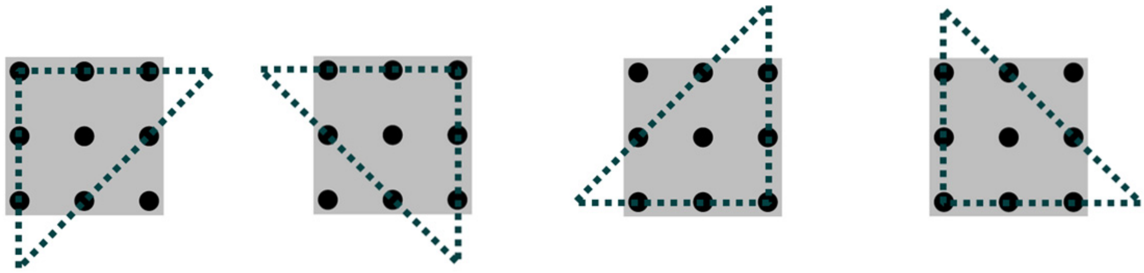
You actually saw one of the four figures below on the screen. Did you recognize the figure when it was shown?

☐ *Yes, I did.*

☐ *I thought I saw something, but I didn't recognize it clearly.*

☐ *No, I did not.*

Which one of the images below do you think you saw? Choose and check only one of them. Please guess even if you don't remember seeing anything.



☐ ☐ ☐ ☐

How confident are you in your answer above?

☐ *Sure*

☐ *Half-sure*

☐ *Guess*

Experiment 3 Materials

RECOGNITION TASK