Research Article

GETTING THE RIGHT IDEA: Semantic Activation in the Right Hemisphere May Help Solve Insight Problems

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Abstract—*Two experiments examined hemispheric differences in information processing that may contribute to solving insight problems. We propose that right-hemisphere (RH) coarse semantic coding is more likely than left-hemisphere (LH) fine semantic coding to activate distantly related information or unusual interpretations of words, and thus more likely to activate solution-relevant information for insight problems. In Experiment 1, after trying to solve insight problems, participants read aloud solution or unrelated target words presented to the left visual field (lvf) or right visual field (rvf). Participants showed greater lvf-RH than rvf-LH priming for solutions for solved problems and priming only in the lvf-RH for unsolved problems. In Experiment 2, participants showed an lvf-RH advantage for recognizing solutions to unsolved problems. These results demonstrate that in a problem-solving context, there was greater activation of solution-relevant information in the RH than in the LH. This activation is useful for recognizing, and perhaps producing, solutions to insight problems.*

This article examines how hemispheric differences in information processing might contribute to solving insight problems. We examine two component processes necessary for problem solving: activation of information that is relevant to the solution and may lead the solver to the correct solution path, and recognition of the solution. Recognition of the solution (or solution-relevant information) can occur when such information is encountered in the environment or when it is activated (or generated) internally.

Although there is no universally accepted definition of what constitutes an insight problem, it is generally agreed that three properties distinguish insight solutions from noninsight solutions: First, when working on an insight problem, the solver experiences an impasse, probably because of being misdirected by ambiguous information in the problem (Dominowski & Dallob, 1995; Smith, 1995). Second, solvers often cannot report the processing that helped them overcome the impasse (Gick & Lockhart, 1995; Ohlsson, 1992). Third, upon solving insight problems, solvers experience a distinctive affective response involving suddenness and surprise—the "aha!" experience (Davidson, 1995; Metcalfe, 1986a, 1986b; Metcalfe & Wiebe, 1987). (For an in-depth discussion of these properties, see Bowden, 1997). In this article, we examine how the first two properties might be explained by processing differences of the cerebral hemispheres.

Researchers have suggested that creative thinking and insight can come from unconscious processing. For example, problem solvers can be influenced by information for which they report no awareness (e.g., Maier, 1931; Rees & Israel, 1935; Safren, 1962; Schunn & Dunbar, 1996). In fact, when a person is solving anagrams, hints presented below the threshold of awareness lead to faster solutions as well as a unique subjective experience similar to the experience found with classical insight problems (Bowden, 1997). In addition, some implicit solution-relevant processing is suggested by the fact that solvers can estimate the coherence or solvability of insight problems they have not solved (Bowers, Regehr, Balthazard, & Parker, 1990; Dorfman, 1990).[1] (For a review, see Dorfman, Shames, & Kihlstrom, 1996.)

It has also been suggested that creative thinking emanates largely from the right hemisphere (RH) (Ornstein, 1977; Springer & Deutsch, 1981). Insight solutions are often viewed as more creative than noninsight solutions because they rely on retrieval of unusual interpretations of problem elements, or on information that may seem only distantly related to the original problem. Some recent descriptions of RH semantic processing are compatible with a role for solving verbal insight problems. For instance, when people comprehend individual words, the RH appears to engage in relatively coarse semantic coding, weakly activating a large field of semantic information, including secondary word meanings (Burgess & Simpson, 1988) and information that is only distantly related to the input word (Beeman et al., 1994; Chiarello & Richards, 1992).[2] In contrast, the left hemisphere (LH) appears to strongly activate a smaller semantic field of information that is closely related to the word in context.

Specifically, greater left-visual-field (lvf-RH) than right-visual-field (rvf-LH) priming occurs when a target word is distantly related to, or related to an unusual interpretation of, a preceding prime word or words (Beeman et al., 1994; Burgess & Simpson, 1988; Chiarello, Burgess, Richards, & Pollock, 1990; Faust & Gernsbacher, 1996; Nakagawa, 1991). Similarly, people recognize distant associations

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1. Solvers can predict solvability better for noninsight problems than for insight problems (Metcalfe, 1986a).

2. Different conclusions have been drawn from work examining asymmetries in semantic processing of pictures. Specifically, it has been claimed that the RH is more rigid in its ability to remember scenes, being less adept at remembering incongruous object arrangements such as those represented in surreal paintings (for a review, see Zaidel, 1994). It is possible that pictorial and lexical semantics operate differently across the hemispheres (Chiarello, 1998). But the results using picture paradigms could also be interpreted as suggesting that the RH is more sensitive than the LH to the global (if not local) context, perhaps relying on distantly related features of the pictured objects to establish global connections, and having more difficulty when such connections are altogether absent. If so, it is not surprising that patients with RH damage have more difficulty than patients with LH damage in detecting incongruities in pictures (Milner, 1958; Warrington & Taylor, 1973). Similarly, less central features of object representations may determine one category exemplar's relation to coexemplars and to the category as a whole—in other words, the exemplar's typicality. Thus, it is not surprising that typicality affects RH processing to a greater extent than LH processing (Cronin-Golomb, 1995; Zaidel, 1987), because the LH may focus on the more central features of an object—say, the wings and beak of a bird—which have a lesser impact on typicality.

between paired words more easily if one of the pair is presented to the lvf-RH (Rodel, Cook, Regard, & Landis, 1992). In addition, patients with RH brain damage (who therefore rely on their intact LH) tend to focus on the most direct, denotative interpretations of words, whereas patients with LH damage (who therefore rely on their intact RH) tend to focus on metaphoric or connotative meanings (Brownell, Potter, Michelow, & Gardner, 1984). Patients with RH damage can have difficulty drawing inferences (Beeman, 1993; Brownell, Potter, Bihrle, & Gardner, 1986) and comprehending discourse that depends heavily on distant semantic associations (for a review, see Beeman, 1998).

We believe that diffuse semantic activation in the RH may provide people with information useful to solving verbal insight problems, whereas the LH's normally effective pattern of activation may make it more susceptible to misdirection if its narrower field of activation is focused on an incorrect interpretation of a problem. Moreover, unconscious processing might play a more salient role in solving insight than in solving noninsight problems because the processing necessary to overcome impasse depends heavily on weak and diffuse RH activation. That is, the solution-relevant RH activation might be too weak and diffuse to reach consciousness, or to be selected to generate a solution (Beeman et al., 1994), yet it might persist after misdirected activation decays (after impasse), allowing it to influence the direction of future solution efforts.

This role proposed for the RH when people solve insight problems is analogous to the role proposed for the RH when comprehenders draw inferences from discourse (Bowden, Beeman, & Gernsbacher, 1995). It appears that information related to predictive inferences is passively activated in the RH, but not selected—that is, it is not activated strongly enough for consciousness or for further more complex processing, such as being included in the comprehender's representation of the discourse. When the inference becomes necessary to maintain coherence, it may be selected by the LH's focused activation, and incorporated into the comprehender's representation (Bowden et al., 1995).

In practice, it is difficult to assign problems to insight and noninsight categories on a principled basis. Clearly, problems lie on a continuum between pure insight problems and pure noninsight problems, and vary greatly in complexity. In the following experiments, we examined hemispheric differences in solution activation by presenting simple insight problems patterned after the Remote Associates Test (RAT; Mednick, 1962). Each of our items consisted of three stimulus words for which participants were asked to generate a fourth word that, when combined with each of the three stimulus words, would result in a word pair used in everyday language (e.g., *pie* / *luck* / *belly—pot*).

We chose to use these compound remote-associate problems for a number of reasons. The RAT was originally developed as a test of creativity and has been widely used to study insight and creative thinking (e.g., Bowers et al., 1990; Dallob & Dominowski, 1993; Dorfman, 1990; Schooler & Melcher, 1995; Shames, 1994; Smith & Blankenship, 1991). Furthermore, problem solvers' success on RAT items has been found to correlate reliably with their success on classic insight problems (Dallob & Dominowski, 1993; Schooler & Melcher, 1995).

Although RAT items may not be as complex as classic insight problems, they exhibit the three properties that distinguish insight solutions from noninsight solutions: They misdirect retrieval processes in the sense that a nondominant meaning of at least one of the words in the triad must be accessed to reach the solution. Memory search for the solution appears to involve both controlled and automatic processing (Ben-Zur, 1989), so that solvers often cannot report the processing that led to the solution. And upon solving RAT items, solvers often have the aha! experience. That is, solving RAT items involves the same component processes critical for insight solutions to more complex problems.

For an investigation of how hemispheric differences in information processing might contribute to solving insight problems, the RAT problems have two advantages over more complex insight problems: They are short, allowing centralized presentation of an entire problem, and they have single-word solutions, allowing presentation of solution or unrelated target words to a single visual hemifield. More complex insight problems cannot be studied in this way.

We used a priming paradigm to test for activation of the correct solution when participants had or had not solved insight problems. Priming was defined as how much more quickly participants read aloud (named) solution target words compared with solution-unrelated target words. The presence of priming for solutions to problems that have not been solved would suggest that unconscious activation exists and that this activation might eventually be useful in reaching insight solutions. It is possible to examine activation in each hemisphere by comparing priming for solution words presented to the lvf-RH or to the rvf-LH even if participants manifest the normal rvf-LH advantage for word reading. Numerous studies have demonstrated qualitatively different patterns of semantic priming for words presented to the rvf versus the lvf, suggesting some independent processing by each hemisphere despite an intact corpus callosum (for a review, see Beeman & Chiarello, 1998).

Our research adds to previous research in several important ways: In previous research, the prime word (or words) and target word were presented with stimulus onset asynchronies (SOAs) of no more than 1,000 ms. In addition, when multiple prime words were presented prior to a target word, participants were not instructed to actively seek an association between the prime words (e.g., Beeman et al., 1994). The following experiments used prime-target SOAs up to 15 s and explicit instructions to attempt to discover the association between the three words. Therefore, we examined hemispheric differences in semantic activation over an extended period of effortful problem solving rather than largely automatic activation occurring within a fraction of a second after the presentation of a word.

EXPERIMENT 1

Method

Participants

Thirty-two right-handed college students at the University of Illinois-Chicago participated for partial course credit. All participants were women, because of constraints on the subject pool, and all were strongly right-handed according to a handedness survey (Bryden, 1982).

Materials

The problems were 144 items similar to items from the RAT (Mednick, 1962). For our items, each of three words in a problem could combine with the solution word to form a word pair used in everyday language (e.g., *high* / *district* / *house—school*), providing participants with a consistent task.

Procedure

For each trial, participants tried to solve one problem, then read aloud one target word. Each trial began with a central fixation cross, and then the three problem words were presented simultaneously in normal horizontal orientation above, at, and below the center of the screen. Participants tried to produce the solution word within a 15-s time limit (determined by pilot studies). After either a solution was produced or time ran out, the problem words were erased, a tone sounded, and the fixation cross reappeared. Then a target word was presented horizontally for 180 ms (with the inner edge 1.5° of visual angle from fixation), and latency to read the target word aloud was measured. Half of the target words were solution words and half were unrelated words (the solutions to other problems); half the solution words and half the unrelated words were presented to each visual hemifield. Participants saw each target word only once over the course of the experiment.

Participants were tested individually. Prior to the experiment, they were given five practice problems with target words. Further explanation was given if required. Participants viewed the screen through a binocular viewer mounted on the table.

Results

On average, participants solved 31.3% (*SD* = 5.9) of the problems within the 15-s time limit. The data from 3 participants were replaced because they solved too few problems (more than 2 *SD*s below the mean).

There were significant main effects of hemifield of presentation, type of target word (solution vs. unrelated), and whether the problem was solved or unsolved. Participants showed the expected LH advantage for naming: Target words presented to the rvf-LH were read 49 ms more quickly than target words presented to the lvf-RH, $F(1, 31) = 21.13$, $p < .0001$. Participants showed overall priming, reading solution target words 56 ms more quickly than they read unrelated target words, $F(1, 31) = 30.82$, $p < .0001$. Participants also read target words 39 ms more quickly following correctly solved problems than following unsolved problems, $F(1, 31) = 8.99$, $p < .005$.

Most important, the amount of priming depended on the hemifield to which the target words were presented, $F(1, 31) = 9.69$, $p < .004$. As illustrated in Figure 1, participants showed greater priming (i.e., reading latencies decreased more) for solution words (relative to solution-unrelated words) presented to the lvf-RH than for those presented to the rvf-LH. This greater priming for lvf-RH presentation occurred for both solved and unsolved problems, $F(1, 31) < 1$.

However, the overall amount of priming did depend on whether participants solved the problems, $F(1, 31) = 18.36$, $p < .0002$. For solved problems, target relatedness interacted with hemifield, $F(1, 31) = 4.61$, $p < .04$. Participants showed 112 ms of priming for lvf-RH solution words, $F(1, 31) = 35.84$, $p < .0001$, and 58 ms of priming for rvf-LH solution words, $F(1, 31) = 9.31$, $p < .005$. For unsolved problems, target relatedness again interacted with hemifield, $F(1, 31) = 5.22$, $p < .03$. Participants showed 44 ms of priming for lvf-RH solution words, $F(1, 31) = 8.50$, $p < .007$, but only 12 ms for rvf-LH solution words, $F(1, 31) = 2.64$, $p < .11$.

Thus, when participants solved problems, activation for the solution was greater in the RH than in the LH. Moreover, when they had not yet solved problems, activation of the solution was found only in the RH. This activation can be considered unconscious in the sense that participants had not used it to produce the solution. It is possible that this

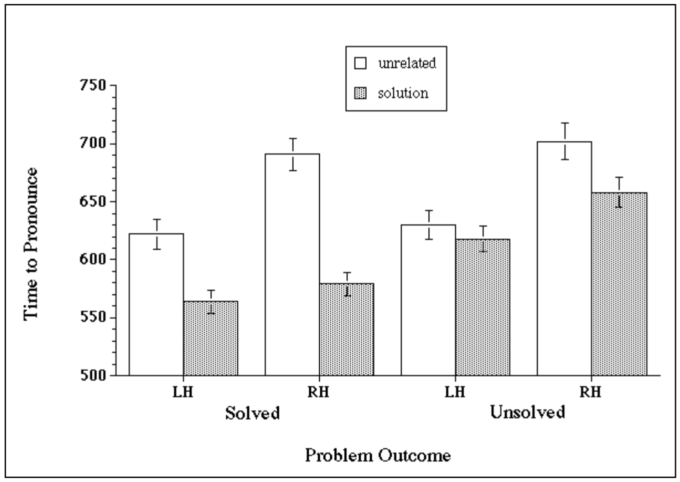

Fig. 1. Naming times for solution and unrelated target words for solved and unsolved problems. LH = left hemisphere; RH = right hemisphere.

activation derived from the solution's distant relation to one or two individual problem words, and was not directly related to the problem-solving process. However, as long as solution-relevant activation exists (apparently, to a greater extent in the RH), it might eventually help people solve the problems. Experiment 2 tested whether the solution activation observed in Experiment 1 might be useful for the second component process of problem solving: recognizing the solution.

EXPERIMENT 2

Method

Thirty-two right-handed college students (16 females, 16 males) at the University of Wisconsin-Parkside participated for partial course credit. The materials and procedure were the same as those of Experiment 1, except that instead of naming the target word, participants indicated with a button press whether the target word was the solution to the problem. This was a direct test of participants' ability to recognize solutions. However, because solution words required a "yes" response, whereas unrelated words required a "no" response, we could not examine priming. Instead, we examined the hemispheric difference in raw response times, keeping in mind that participants normally display an rvf-LH advantage when responding to words. Half the participants responded with their left hands, and half with their right. Instead of using a binocular viewer, as in Experiment 1, participants were positioned in a chin rest–head holder.

Results

On average, participants solved 32.8% (*SD* = 7.2) of the problems within the time limit. The data from 5 participants were replaced because they solved too few problems (more than 2 *SD*s below the mean).

Latencies of correct responses were analyzed. Most important, after unsolved problems, participants responded more quickly to lvf-RH words than they did to rvf-LH words, $F(1, 31) = 14.62$,

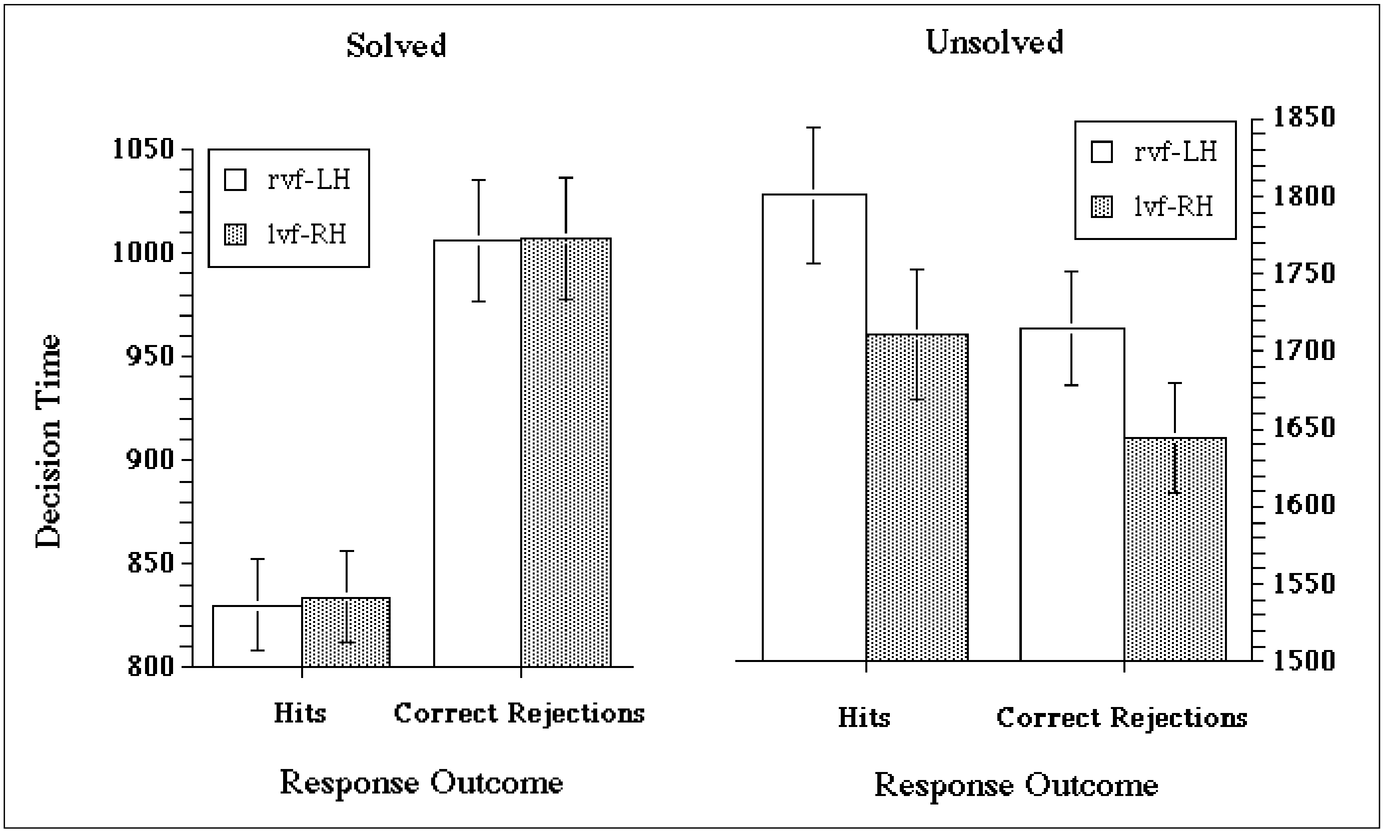

Fig. 2. Response times for hits and correct rejections, for solved problems (left panel) and unsolved problems (right panel). LH = left hemisphere; RH = right hemisphere; lvf = left visual field; rvf = right visual field.

$p < .0006$. This result is in contrast to the typical rvf-LH advantage for responding to words, and was found for both hits ("yes" responses to solutions) and correct rejections ("no" responses to unrelated targets). After solved problems, there was no effect of hemifield of presentation, $F(1, 31) < 1$, so hemifield of presentation interacted with whether the problem was solved or unsolved prior to seeing the target word, $F(1, 31) = 7.23$, $p < .011$ (see Fig. 2).

Participants responded to target words 798 ms more quickly after solved problems than after unsolved problems, $F(1, 31) = 135.81$, $p < .0001$. Participants made hit responses marginally more quickly (49 ms) than they made correct rejections, $F(1, 31) = 2.88$, $p < .10$. Type of response (hit or correct rejection) interacted with whether participants solved the problems, $F(1, 31) = 18.65$, $p < .0001$: Participants made hits more quickly than correct rejections after solved problems, but made correct rejections more quickly than hits after unsolved problems.

No significant effect was found for response hand, $F(1, 30) < 1$. The lvf-RH advantage was found regardless of response hand (74 ms for left-handed responses and 88 ms for right-handed responses). There was no significant effect of sex of participant, $F(1, 30) < 1$. Both women (76 ms) and men (85 ms) showed the lvf-RH advantage.

We used a sensitivity analysis (d') from signal detection theory to examine accuracy of recognition responses. After solving problems, participants responded with equal sensitivity to the target words in the rvf-LH and lvf-RH (rvf-LH $d' = 3.54$, 94.5% correct; lvf-RH $d' = 3.28$, 93.9% correct), $F(1, 31) < 1$. After failing to solve problems, they responded with marginally greater sensitivity in the rvf-LH ($d' = 2.14$, 83.8% correct) than in the lvf-RH ($d' = 1.81$, 79.3% correct), $F(1, 31) = 2.56$, $p = .12$. The lvf-RH advantage for response latency was not correlated with the rvf-LH advantage for accuracy, $r(32) = -.05$. Thus, participants were not sacrificing accuracy for speed when responding to lvf-RH target words.

GENERAL DISCUSSION

Experiment 1 showed that when participants had solved insight problems, activation of the solution was stronger in the RH than in the LH. Even when participants had not yet solved insight problems, they had some solution-related activation in the RH, but not in the LH. The fact that problem solvers have solution-related activation for problems they have not yet solved is consistent with the belief that unconscious processing contributes to insight solutions (Bowden, 1997). Experiment 2 showed that problem solvers can use this RH activation to make faster solution judgments on words presented to the lvf-RH than on words presented to the rvf-LH.

Solution-related priming has previously been documented for obscure words that participants could not produce in response to the words' definitions (Yaniv & Meyer, 1987). The current data extend this finding to insight problems, and are in accord with unpublished data from Shames (1994, cited in Dorfman et al., 1996) and a preliminary study of RH involvement in insight (Fiore & Schooler, 1998). Also, the fact that information related to solutions of insight problems is more likely to be activated in the RH than in the LH is consistent with previous data about semantic priming asymmetries, and specifically with the theory that the RH coarsely codes meanings of words: In response to input words, the RH weakly activates large semantic fields of related information, including information only distantly related to the input words. This provides only a coarse interpretation of each word, but the large semantic fields from multiple words in discourse, or from an insight problem, are more likely to overlap than the smaller semantic fields generated in the LH (Beeman, 1998; Beeman et al., 1994). Our research adds to previous research by demonstrating hemispheric differences in semantic activation over an extended period of effortful problem solving rather than only within a fraction of a second after the presentation of a word. Moreover, the lvf-RH priming advantage for solved problems (Experiment 1) and the lvf-RH advantage in recognizing solutions (Experiment 2) suggest that the activation of distantly related information might contribute to solving insight problems. When solution candidates are presented to problem solvers, the RH activation helps in judging whether those candidates are indeed solutions. It is possible that if solvers continued to work on these problems without solution candidates being presented, they could use this weak RH activation to help generate solutions.

Although problems similar to the ones used here have been used to study problem solving, creativity, and insight in previous experiments (e.g., Ben-Zur, 1989; Bowers et al., 1990; Dorfman, 1990; Shames, 1994, cited in Dorfman et al., 1996; Smith & Blankenship, 1991), classical insight problems are generally more complex, and solving them undoubtedly requires additional component processes not addressed in the present experiments. This research does demonstrate that RH activation can aid in two of the processes involved in problem solving: directing retrieval of solution-relevant information and recognizing the solution or solution path.

Schooler, Fallshore, and Fiore (1995) suggested that with insight problems, solvers have difficulty initially recognizing the correct approach, and therefore are likely to activate solution-irrelevant information rather than solution-relevant information in memory. What is needed is to disengage retrieval processes from irrelevant information and redirect them to solution-relevant information. This is difficult and takes time (Bowden, 1985). As mentioned earlier, it is possible that activation of solution-relevant remote associates in the RH derives from the solution's distant relation to one or two individual problem words, and is not directly related to the problem-solving process. However, if the RH simply sustains this activation until after the misdirected activation in the LH has subsided, it might still help people solve problems. The present experiments suggest that the necessary redirection of the search process might benefit from the activation of remote associates that already exists in the RH.

We propose that RH activation might help people solve insight problems in the following way: Insight problems contain ambiguous features that misdirect retrieval toward information that is strongly related to the typical interpretation of words in the problems, but does not lead to solution. Because of the LH's relatively fine semantic coding, the misdirection causes strongly focused activation of such information in the LH—to the exclusion of solution-relevant information. Because of the RH's relatively coarse semantic coding, there is likely to be activation of solution-relevant information as well as misdirected information in the RH. However, problem solvers have difficulty using this weak activation. The current data cannot determine whether the solution-relevant activation in the RH is simply too weak to allow solvers to generate the solution, or is blocked by stronger, misdirected activation. We do know that the RH activation is too weak to be reported. Further, we speculate that strong but misdirected activation, primarily in the LH, prevents solvers from generating the solution, and must subside for solvers to overcome impasse. When the misdirected activation has subsided, the weak solution-relevant activation in the RH could be stronger than competing activation, allowing it to be selected for further processing, or to influence future problem-solving efforts. Once retrieval is correctly redirected, the solution (or solution path) is soon obvious. When this happens, solvers may experience the aha! of insight. In contrast, when problems do not misdirect retrieval, the strong activation in the LH likely is focused on the correct interpretation from the start. In these cases, solvers are less likely to experience impasse, contributions from unconscious processing, and feelings of insight.

We do not claim that the RH is solely responsible for producing the solution; indeed, we believe the LH plays a major role in selecting a solution to output, or in executing further operations along the solution path. It is also possible that insight problems could be solved entirely in the LH. The LH could simply initiate a new search after impasse, essentially moving its focused spotlight of activation around the problem space until the solution is found. However, given that the solution, or solution-related information, is already activated in the RH, the optimal problem-solving strategy would make use of it.

SUMMARY

Achieving insight to solve complex problems is an important and multifaceted behavior. The present experiments demonstrate that coarse semantic coding in the RH is well suited to two component processes that contribute to producing creative or insightful solutions: activating distantly related but still solution-relevant information and recognizing the solution or solution path. We suggest that when a person is working on an insight problem, RH coarse semantic processing is more likely than LH fine semantic processing to activate solution-relevant information, just as it is more likely to activate distantly related information or less common interpretations during language comprehension in general.

We also suggest that RH activation persists in the absence of awareness because it is weak and diffuse (and perhaps overshadowed by stronger misdirected activation in the LH). Although it is not clear whether the RH can directly generate the solution, RH activation can still be useful for guiding retrieval attempts or recognizing the solution when it is encountered.

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