

Evolutionary and Neurocognitive Approaches to Aesthetics, Creativity, and the Arts

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CHAPTER 13

Neural Correlates of Creative Cognition

Oshin Vartanian and Vinod Goel

INTRODUCTION

Currently, there is general consensus that creativity is not mediated by a single process or mechanism, but that it is brought about by the interaction of several cognitive, emotional, and social processes (see Sternberg, 1999). Of particular interest to us are some of the component processes that mediate creative cognition, such as divergent thinking, hypothesis generation, and set shifting or lateral transformations. Specifically, we are interested in discovering the brain areas that each of these processes can be mapped onto. This goes hand in hand with a resurgence of interest in the role of the brain in creative cognition (e.g., Feist, 2004). Equally important is determining whether the cortical structures that underlie creative cognition also mediate other related phenomena that have been linked to creativity, such as insight solution. The basic reasoning behind this line of research is that discovering the mappings of component processes of creativity onto cortical networks will provide a first step in constructing a model for understanding how these networks or structures interact in bringing about creative cognition.

CREATIVITY AND HEMISPHERIC ASYMMETRY

Much of the earlier work that was conducted in investigating the neural bases of creativity was motivated by some version of a hemispheric asymmetry hypothesis (see Martindale, 1999). These hypotheses were based on physiological evidence that linked the right hemisphere

to engagement in creative tasks (e.g., Martindale, Hines, Mitchell, & Covello, 1984). However, the mechanisms that may underlie this hemispheric difference remain to be explicated. After conducting an extensive review of the historical and contemporary work in neuroscience and neuropsychology on hemispheric asymmetry, Springer and Deutsch (1998) suggest that on the whole, the differences in the modes of information processing by the left and right hemispheres can be characterized as "analytic" and "holistic" respectively. They argue that the traditional association of the left hemisphere with linguistic processing and the right hemisphere with spatial processing can be subsumed under the more global analytic and holistic banners. In addition, they emphasize that the two hemispheres do not always process information in the expected manner, and that it is the task rather than the stimuli that determines the mode of processing. The observation that task demands rather than the nature of the stimuli trigger the involvement of a particular hemisphere has found recent support in the literature (Stephan et al., 2003).

Along similar lines but using a different terminology, Goldberg and colleagues have argued that what engages the left and right hemispheres respectively is the extent to which a situation involves the engagement of routine versus novel cognitive strategies (Goldberg, Podell, & Lovell, 1994). They introduce the distinction between *veridical* and *adaptive* decision making to highlight this key functional difference between the right and left prefrontal cortex (PFC) (Goldberg & Podell, 1994). Veridical decision making is engaged in the process of identifying a correct response, and it is determined primarily by the parameters of the situation and independently of the decision maker. Thus, when a person is engaged in a problem with a recognizable structure and a predetermined correct response, then veridical decision making occurs. Typical tasks of this sort are the Wisconsin Card Sorting Task and the Tower of London Task. In contrast, adaptive decision making occurs when there are no readily available patterns to be extracted from the task environment. In such cases, the priorities of the agent become important in choosing the correct course of action. These constitute the majority of situations in open-ended settings in the real world where the agent interacts with the environment in choosing one course of action among many.

Based on the performance of patients with focal brain lesions on a test designed to measure differences in processing between the left and right frontal cortex, Goldberg and colleagues have shown that the decisions of the left frontal cortex are more likely to be in tune with the parameters or features of the environment, whereas those of the right frontal cortex are more likely to deviate from environmental cues

and are more likely to be influenced by the preferences of the agent (Goldberg & Podell, 1999; Goldberg, Podell, Harner, Riggio, & Lovell, 1994). The implication of right prefrontal cortex in mediating internally motivated preferences can be contrasted with an alternative view that the emotional brain mediates the interaction between preferences and cognitive demands via orbitofrontal cortex (e.g., Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, & Lee, 1999). Nevertheless, Goldberg has argued that the differential performance of patients with frontal lesions supports the notion that the left PFC is more likely than the right PFC to be influenced by the patterns and features of the environment and explains why the right hemisphere is more likely to be engaged in cognitively novel situations where such patterns or features are absent or fail to be detected. In essence, Goldberg's work offers a "hemispheric specialization" account of laterality.

In contrast, Gazzaniga (1985, 1995, 1998) has proposed a rather different model for hemispheric asymmetry. Based on data from split-brain patients, he has demonstrated that following surgical division of the hemispheres, the ability of the left hemisphere to engage in problem solving and reasoning remains intact, whereas the ability of the right hemisphere is seriously impoverished. In a recent demonstration of this, Wolford, Miller, and Gazzaniga (2000) tested the performance of split-brain and focal-lesion patients in a task where they were required to predict the occurrence of events based on exposure to previously presented sequences. However, unbeknownst to the subjects, the sequences that were presented to them were random. The results of this task demonstrated that the left frontal cortex performed worse because of its tendency to extract patterns despite the random nature of the sequences. Based on such data, Gazzaniga postulates the existence of a structure called the "interpreter" in the left hemisphere whose function is to make sense of the environment by extracting patterns—be they causal, logical, or statistical—from events. The right hemisphere, in contrast, is not ascribed such pattern extraction tendency. In fact, Gazzaniga (2000) argues that the right hemisphere performs better than the left hemisphere because it "approaches the task in the simplest possible manner with no attempt to form complicated hypotheses about the task" (Gazzaniga, 2000, p. 1316). In fact, in general, animals perform better than humans on this task as well, presumably because they pursue a strategy similar to the one used by the right hemisphere. Thus, Gazzaniga's account can be best understood as a "hemispheric dominance" account whereby the left hemisphere is viewed to mediate most types of intelligent behavior, with the right hemisphere performing a supporting role, such as processing spatial information (Corballis, 2003; Gazzaniga, 2000).

NEURAL BASES OF HYPOTHESIS GENERATION

We have conducted a series of fMRI studies to elucidate the neural bases of creative cognition. As mentioned above, creativity can be broken down into component processes, and research has shown that one of the features of creative cognition that sets it apart from routine problem solving is the ability to generate hypotheses (Vartanian, Martindale, & Kwiatkowski, 2003). We were interested in determining whether the right and left PFC would be engaged differently as a function of hypothesis generation, especially those requiring set shifts (lateral transformations). For our first study, we used a modification of Guilford's (1967) classic Match Problems. Briefly, this task involves presenting the subject with a particular configuration of matches that make a number of complete squares. On each trial, the subject is instructed to remove a particular number of matches to generate another number of complete squares. The dependent variable is the number of solutions that a subject can generate in response to each problem instruction, with higher solutions being indicative of higher divergent thinking ability.

Guilford (1967) argued that the key feature of performing well on this task is the ability to engage in *set shifts*. Set shifts are analogous to what Goel (1995) has referred to as "lateral transformation." A lateral transformation is a movement from one state in a problem space to a horizontally displaced state rather than a more detailed version of the same state (i.e., vertically displaced state). Mental representations that are imprecise, ambiguous, fluid, indeterminate, vague, etc., facilitate lateral transformations. Mental representations that are overly precise and concrete can hinder lateral transformations. Lateral transformations allow the problem solver to remain noncommittal about the state he or she is in and to move easily between them. As such, lateral transformations are necessary for overcoming set effects and facilitate *widening* of the problem space.

Goel (2002) has argued that indeterminate mental representations, such as those that are described by set shifts or lateral transformations, are mediated by right PFC. We tested this hypothesis by presenting subjects with two versions of Match Problems in the scanner (Goel & Vartanian, 2005). In each trial of the divergent version, they were presented with a match problem and asked to determine the number of ways in which it could be solved. We argued that this required the generation and verification of hypotheses. In contrast, in baseline trials, subjects were presented with hypothetical solutions to match problems and instructed to determine whether the solution was correct. We argued that the baseline condition required the verification

of hypotheses only. Therefore, a comparison of Match Problems versus baseline trials would highlight those brain areas that are involved in hypothesis generation. The results indicated that hypothesis generation activated left dorsal lateral PFC (BA 46) and right ventral lateral PFC (BA 47) (Figure 1).

The above comparison of Match Problems vs. baseline trials isolated brain regions involved in hypotheses generation in set-shift problems. This generation process will include both lateral and nonlateral transformations. To identify specifically the neural correlates of lateral transformations, we isolated match problems that had correct solutions and compared those for which at least one correct solution was generated versus those for which no correct solution was generated (Successful vs. Unsuccessful). This resulted in activation in right ventral lateral PFC (BA 47), left middle frontal gyrus (BA 9), and left frontal pole (BA 10). This result demonstrated that although left dorsal lateral PFC (BA 46) and right ventral lateral PFC (BA 47) mediate hypothesis generation in Match Problems, it is only the latter area that also mediates generating hypotheses that require set shifts.

In our final analysis, we examined the proportion of responses that were generated on each trial of Match Problems. This was done because there is a conceptual difference between generating *any* hypothesis versus generating *multiple* hypotheses. In essence, this second analysis was conducted to highlight those brain regions where activation increased in response to generating more hypotheses. The results revealed that activation in right dorsal lateral PFC (BA 46) and cerebellum covaried as a function of the number of solutions that were generated in response to match problems (Figure 2). This activation can be attributed to at least three different processes, namely, working memory (WM), cognitive monitoring, and conflict resolution. Activation in right dorsal lateral PFC (BA 46) could be due to increased WM involvement because as one generates more hypotheses, one has to maintain a larger amount of information in mind. Alternately, this activation could be due to cognitive monitoring because generating more hypotheses places a larger supervisory demand on the system. Finally, as one generates more hypotheses, there is likely to be conflict in terms of what the correct response should be. Of course these three processes are not mutually exclusive, and data from imaging studies have linked activation in right dorsal lateral PFC (BA 46) to all three processes (Barch et al., 1997; Braver & Bongiolatti, 2002; Braver et al., 2001; Cohen et al., 1997; Goel, Buchel, Frith, & Dolan, 2000; Leung, Gore, & Goldman-Rakic, 2002; Zurovski et al., 2002).

The results from our second fMRI study demonstrated that the findings from Match Problems can be extended to the verbal domain as

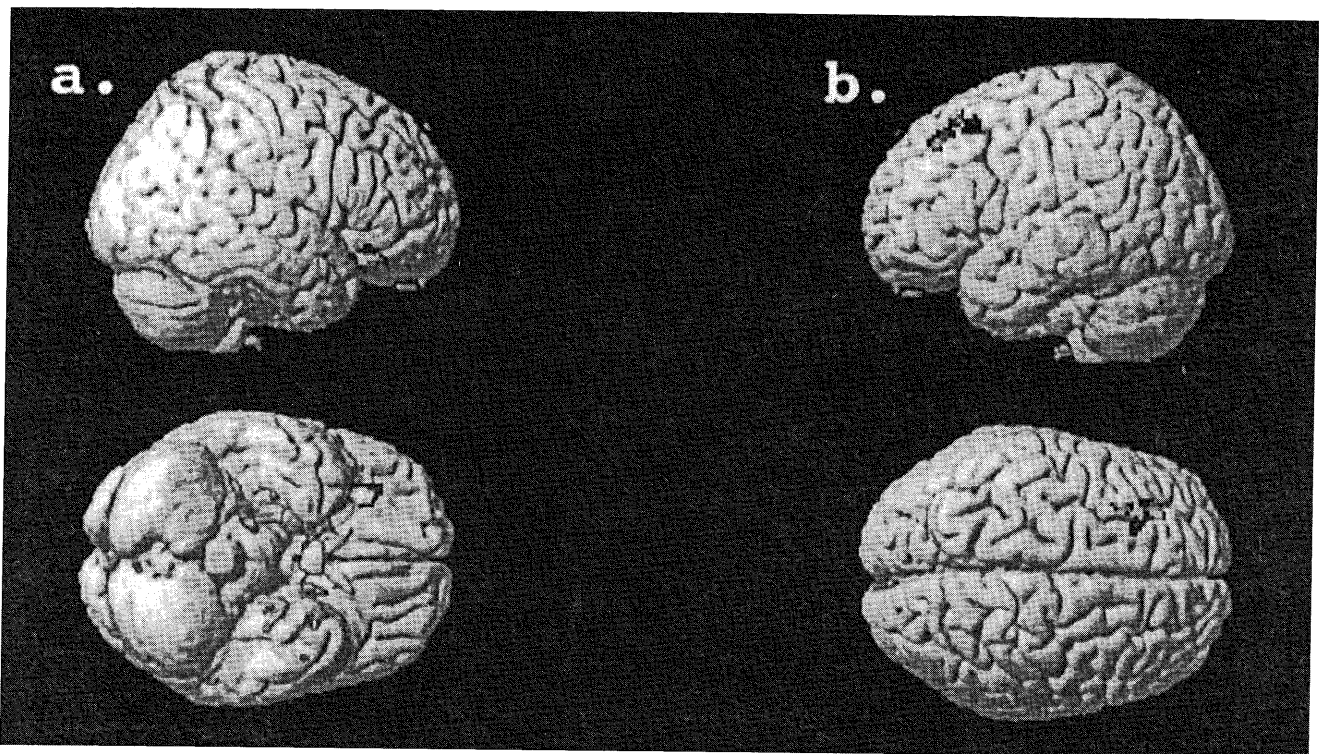


Figure 1. A comparison of Match Problems vs. baseline trials revealed significant activation in (a) right ventral lateral PFC (BA 47) and (b) left dorsal lateral PFC (BA 46).

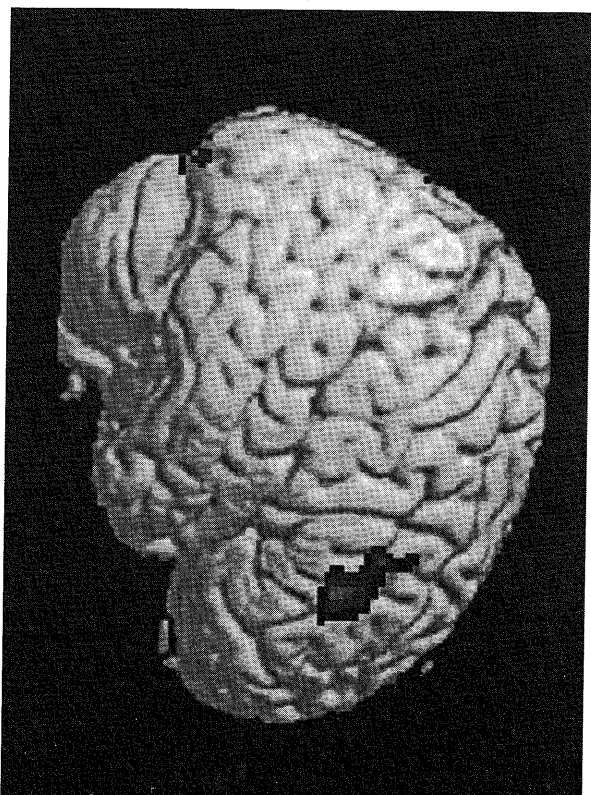


Figure 2. Activation in right dorsal lateral PFC (BA 46) and cerebellum covered as a function of the number of solutions in Match Problems.

well (Vartanian & Goel, 2005). For this study, we presented subjects with different types of anagram problems in the scanner. Anagram problems require rearranging strings of letters (e.g., KEROLJ) to form words (JOKER), and they are known to embody a hypothesis generation component (Greeno, 1978). Our results demonstrated that solving anagrams in a relatively unconstrained way (e.g., “Can you make a word with CENFAR?”) compared to a condition where solutions were restricted to particular semantic categories (e.g., “Can you make a country with CENFAR?”) activated a network of areas including the right ventral lateral PFC (BA 47). The combined results from Match Problems and the anagram task demonstrated that hypothesis generation in relatively more open-ended settings activates a network that includes right ventral lateral PFC (BA 47), regardless of the spatial or linguistic nature of the stimuli.

NEURAL BASES OF INSIGHT SOLUTIONS

Historically, there has been a close relation between insight problems and problems that require creative solutions, although the mechanisms that are thought to mediate these two types of problem solving are considered to be different (see Sternberg & Davidson, 1996). For our

purposes, it is interesting to determine whether insight problems activate the same neural structures as do divergent thinking tasks. This may inform us about whether creative and insight problems share any underlying cognitive mechanisms. Recently, a number of imaging studies using different methods have investigated the neural correlates of insight, with surprising convergence in their results. In an earlier study, Schneider et al. (1996) presented their subjects with solvable or unsolvable anagrams in the PET scanner. The authors reasoned that solving the former would result in a feeling of insight, and their results demonstrated that engagement in solvable anagrams was associated with increased regional cerebral blood flow (*r*-CBF) to the hippocampus. In a more recent fMRI study, Luo and Niki (2003) presented their subjects with Japanese riddles that they knew they could not solve (e.g., The thing that can move heavy logs, but can not move a small nail) and then presented them with the answer (i.e., river) in order to generate an experience of insight. The results showed that activation in the right hippocampus was associated with the experience of insight. Finally, in the most recent fMRI study on this topic, Jung-Beeman et al. (2004) presented their subjects with items similar to those from Mednick and Mednick's (1967) Remote Associates Test (e.g., pine, crab, sauce), in response to which subjects had to generate a single word that would be common to all three (i.e., apple). Because this problem can be solved with or without insight, the authors relied on subjective reports to determine whether the problems were in fact solved with insight or not. The results revealed that solving problems with a subjective feeling of insight activated the right superior temporal gyrus. The results of these three imaging studies on insight converge on the role of the right temporal lobe and in particular the hippocampus in insight solutions. Equally important, they demonstrate that insight problems activate different neural structures than do hypothesis generation tasks.

A NEURAL MODEL FOR CREATIVE COGNITION

Based on the evidence presented above, a few useful trends have emerged for understanding the neural bases of creative cognition. First, the neural bases of creative cognition, in particular those related to hypothesis generation including set shifts (lateral transformations), differ from the neural correlates of insight solutions. Specifically, insight problems seem to engage consistently the right temporal lobe and the hippocampus. Insight and creative problems differ in at least two important ways. First, whereas it is still unclear whether insight solutions are all-or-nothing phenomena or occur as a result of the gradual accumulation of information (e.g., Novick & Sherman, 2003),

creative problems tend to involve movement through successive hypothesis generation-and-evaluation cycles until satisfactory solutions are reached (e.g., Eysenck, 1993). Second, strictly speaking, insight problems are not open-ended because they entail the discovery of a predetermined correct response, whereas some types of creative problems are open-ended in that they allow for the discovery of multiple correct solutions. Third, the role of emotion may differ in insight and creative problems, especially in the final phase of solution recognition, and this may give rise to different neural profiles for the two processes. For example, arrival at an insight solution tends to be accompanied by an emotional component (Gick & Lockhart, 1996), whereas this effect may be less general regarding creative solutions.

In the second trend, left and right hemispheres appear to function differently based on the nature of the problem at hand. The left PFC is more likely to be engaged when a problem allows for the extrapolation of patterns to reach correct solutions (e.g., Wolford et al., 2000). In line with this thesis, our lab has accumulated considerable evidence to support the critical role of the left PFC in extracting logical patterns in reasoning tasks (Goel & Grafman, 2000; Goel & Dolan, 2003, 2004; Goel, Gold, Kapur, & Houle, 1998; Goel, Shuren, Sheesley, & Grafman, 2004). In contrast, the right PFC is more likely to be engaged by problems that do not have a single predetermined correct response, but allow the agent to generate multiple strategies (i.e., plans, hypotheses) that will guide movement in the problem space toward a solution (Goel & Grafman, 2000; Goel & Vartanian, 2005). Therefore, it is perhaps not surprising that situations that appear novel to the agent, or real-life situations that provide the agent with multiple paths of action, engage the right PFC (Burgess, 2000; Goldberg et al., 1994).

Third, rather than having a unified role, different regions of right PFC may have different functions in the creative process. Specifically, the *ventral* aspect of right PFC appears to mediate the generation of set-shift hypotheses (Figure 1), whereas the *dorsal* region of right PFC appears to mediate the executive aspects (e.g., conflict resolution, cognitive monitoring, WM, etc.) of the creative process. This dissociation between the ventral and dorsal aspects of right PFC is consistent with evidence from patient studies. For example, the critical role of the right ventral PFC in set-shift hypothesis generation was reinforced in a study of patients with focal brain lesions and normal controls on Match Problems (Miller & Tippett, 1996). The authors administered two types of match problems to their subjects. One type required set shifting to arrive at correct solutions, whereas the other type consisted of problems that required straightforward match removal for solution. They reported that patients with focal right-PFC lesions were impaired

specifically on those match problems that required set shifts. This selective impairment in performance was especially apparent in patients with lesions to right *ventral* (as opposed to dorsal) PFC, suggesting that this region is not only critical but necessary for set-shift transformations.

Additional support for the functional distinction between the ventral and dorsal aspects of right PFC is available from imaging studies. For example, Newman, Carpenter, Varma, and Just (2003) investigated the neural correlates of engagement in the Tower of London Task. Their results demonstrated that engagement in plan generation (which would involve a generation component) activated the right PFC, including right inferior frontal gyrus and dorsal lateral PFC. However, varying task difficulty (i.e., number of moves to solution), and thereby cognitive load, modulated activity in dorsal lateral PFC, but not in the right inferior frontal gyrus. This again suggests that right inferior frontal gyrus is involved in the generation of solutions per se, whereas the involvement of right dorsal lateral PFC is a function of cognitive load or executive control.

These trends can be used in the construction of a model for creative cognition, particularly because there is an indication that cognitive flexibility can be understood in two different ways (Eslinger & Grattan, 1993; Feist, 2004). First, within the context of veridical problems where one is in search of a predetermined correct solution, cognitive flexibility involves an ability to react to environmental feedback as one moves toward the correct solution. In contrast, in the context of adaptive problems, cognitive flexibility involves the ability to generate cognitive strategies (i.e., plans, hypotheses) that can be pursued until solutions are reached. This distinction has been referred to as reactive vs. spontaneous cognitive flexibility (Eslinger & Grattan, 1993), and it may involve the left and right (ventral) PFC respectively. Imaging and patient studies can be designed to study the nature of this possible double dissociation. Second, apart from a divergent production (hypothesis generation) component, creative tasks also involve an executive component that can monitor and guide the results of the generative process, and there is reason to believe that this involves the dorsal aspect of right PFC (Goel & Vartanian, 2005). Therefore, creative cognition appears to involve at least two aspects of right PFC that are integral components of a larger cortical framework.

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