**The Cognitive Neuroscience of Insight and its Antecedents**

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 On August 5th, 1949, a fire burned out of control in Mann Gulch in Montana. A team of firefighters led by Wag Dodge parachuted into the gulch on the side opposite the fire. As the firefighters worked their way down the side of the gulch, the fire, whipped by fierce winds, suddenly jumped across the canyon and lit the grass below the men. The winds continued to propel the fire which raced up the incline toward the firefighters. The men started making their way uphill away from the fire, but Dodge soon realized that the fire was approaching them too quickly for them to outrun it. In a flash of insight, he suddenly stopped running and lit the grass in front of him. This new fire burned the ground bare. He then lay down on the burnt ground and waited as the fire in back of him approached, surrounded him, and then passed him. Almost all the other firefighters died that day.

 Dodge’s solution to this problem was not new. The Indians of the Great Plains learned to use this technique long before Dodge did. But Dodge apparently never knew this. His solution was, for him, a remarkable and novel example of creative insight. He solved the problem of avoiding being burnt alive by doing the least obvious thing – setting a fire. And importantly, he was able to achieve this sudden insight in an emergency situation.

 Most people are familiar with the phenomenon of *insight,* the sudden solution to a seemingly intractable problem or a sudden comprehension that allows one to see a situation in a new light. Such insights are powerful experiences because they come unexpectedly and because they reorganize one’s thoughts and perceptions in novel ways. However, even though sudden insights seem to be disconnected from the ongoing stream of thought and appear to come from nowhere, a recent series of behavioral and neuroimaging studies by my colleagues and I show that an insight is actually the culmination of a series of brain states and processes operating at a number of time scales.

The Approach

 Obviously, it isn’t practical to put test subjects in a brain scanner and wait until they have an insight. Instead, we have measured subjects’ brain activity while they solved a series of simple verbal problems that can be solved either by insight or by a conscious, methodical, strategy which cognitive psychologist refer to as *analytical*. We presented subjects with a series of *compound remote associates* problems (Bowden & Beeman, 2003), each of which consists of three words (e.g., *pine, sauce, crab*). The subject’s task is to derive a fourth word that can form a compound or familiar phrase with each of the three words of the problem (i.e., *apple* – *pineapple, applesauce, crabapple*). Each time a subject solves one of these problems, he or she is prompted to indicate whether the solution had popped into awareness as a sudden insight or whether the solution had been the result of methodical, conscious, hypothesis testing. We sort each subject’s solutions according to these solution methods and then examine and compare the corresponding patterns of brain activity.

The Neural Correlate of the “*Aha!* Moment”

 Our first neuroimaging study of insight (Jung-Beeman et al., 2004) included two separate experiments, one involving measuring neural activity with high-density electroencephalograms (EEG), the other measuring blood flow in the brain using functional magnetic resonance imaging (fMRI). These two techniques are complimentary, because EEG has excellent temporal resolution accompanied by modest spatial resolution, while fMRI has excellent spatial resolution but only modest temporal resolution. Together, these two techniques allowed us to localize insight in the brain in both space and time.

 Comparing neural activity for insight and analytic solutions at the point of problem solution, fMRI revealed one statistically significant brain activation. There was greater brain activity for insight solutions in the anterior superior temporal gyrus of the right temporal lobe. This was confirmed by EEG, which found a burst of high-frequency (i.e., gamma band) neural activity measured in electrodes over this location occurring at about the point in time at which the insight popped into awareness. Interestingly, the right anterior superior temporal gyrus is a brain area implicated in integrative conceptual processing, such as occurs in the processing of metaphors and jokes.

Sensory Gating

 An additional finding turned up in the study of Jung-Beeman et al. (2004) that was a surprise. The EEG data showed a burst of insight-related alpha-band (approximately 10 Hz) activity at about 1.5 seconds before the button-press response indicating that a problem had been solved. This burst of alpha-band activity occurred just before the burst of gamma-band activity that coincided with the problem solution popping into awareness and was detected over right occipital cortex. Ever since the 1920s, posterior alpha has been associated with cortical idling or inhibition of the visual system. Specifically, alpha is inversely proportional to cortical activity and, in the case of posterior alpha, it represents gating or reduction of sensory inputs.

A Hemispheric Model of Insight

 Although this finding of sensory gating was a surprise, it fit into our emerging model of insight problem solving. According to this view (Jung-Beeman et al., 2004), the cerebral hemispheres process semantic information differently from each other. Specifically, the left hemisphere performs *fine semantic coding* in which a concept activates, by association, a small number of closely related concepts. For example, the concept *table* might activate only *chair* and *lamp.* In contrast, the right hemisphere performs *coarse semantic coding* in which a concept weakly activates a larger number of more distantly associated concepts. In this case, for example, the concept *table* might activate *water* (i.e., water-table), *payment* (for “paying under the table”), *ping-pong* (i.e., ping-pong table), etc. According to our model, an insight occurs when attention switches from closely-associated, strongly-activated, left-hemisphere solution candidates to a weakly activated, distantly associated, right-hemisphere solution. We hypothesized that the alpha burst reduced potentially interfering visual inputs to the right hemisphere, thereby facilitating the retrieval of a weakly activated solution. A particularly interesting aspect of this model is that, if this interpretation is correct, the burst of sensory-gating alpha reflects the brain's sensitivity or “awareness” of a subconscious solution represented in the right hemisphere.

Preparatory Effects

 The presence of the alpha burst showed that, even though the phenomenal awareness of an insight is sudden, discrete, and unpredictable, the “*Aha!*” itself has a neural antecedent which presumably facilitates the insight. But the existence of this antecedent suggested the possibility that there were additional upstream antecedents. We tested this notion in a subsequent EEG/fMRI study (Kounios et al., 2006) using the same set of compound remote associate problems. This study examined neural activity during the 2 seconds immediately preceding the presentation of each problem. In the EEG study, when ready to view the next problem in the sequence, subjects made a bimanual button-press which initiated the display of the problem 1 second later. (For technical reasons, the inter-trial intervals were randomly varied and not subject-controlled in the fMRI study.)

 Most of the results from the EEG and fMRI studies closely corresponded. During the pre-problem interval, neural activity was greater in a number of brain areas preceding problems that a subject would subsequently solve with insight (relative to those solved analytically). These areas included the anterior cingulate, which is closely associated with cognitive control mechanisms such as those involved in attention switching and detection of competing cognitive and response representations, and bilateral temporal-lobe activity consistent with the priming of left- and right-hemisphere areas involved in semantic processing. In contrast, results for the interval preceding problems subsequently solved analytically revealed increased activity in the visual system.

 Together, these results suggest neural preparatory mechanisms that bias a person to solve an upcoming problem either with insight or analytically. Insight solving is facilitated by priming of the anterior cingulate, which is involved in attention switching and the detection of alternative solution candidates, and bilateral temporal areas associated with semantic processing. Analytical solving is associated with increased activity in the visual system which may simply reflect greater attention to the monitor on which the problem will subsequently be displayed. Another way of thinking about this is that neural preparation for insight solving involves focusing attention inwardly on internal conceptual representations and on processes responsible for the cognitive flexibility necessary for insight while preparation for analytical processing involves focusing attention outwardly.

 So far, we've traced the antecedents of insight backward in time from the gamma-band burst reflecting the insight itself to the immediately preceding alpha-band burst reflecting sensory gating, to the preparatory effects preceding the presentation of the problem. These antecedents constitute a chain of events that enable an insight to occur. But how far back in time can these antecedents be traced? What is the matrix from which this chain of events emerges? To investigate this question, we looked as far back in time as we could – *resting-state brain activity*.

Resting-State Brain Activity

 Cognitive activity can be roughly categorized into two types: *directed* and *undirected*. The vast majority of studies of human cognition, whether behavioral or neuroscience, examine the directed form of cognition in which a subject is given a specific task to perform. In contrast, studies of undirected cognition, though growing in number, are still in the minority. Undirected cognition is the spontaneous mental activity that a person engages in when there is no explicit task or goal. Colloquially put, it is daydreaming. In cognitive neuroscience, it is called *resting-state brain activity.*

 Such resting-state brain activity has been a focus of clinical EEG research for many years (John et al., 1988) because of evidence that individual differences in resting-state activity reflect specific neurological and psychiatric disorders. More recently, fMRI studies of nonclinical subjects indicate that individual differences in resting-state activity correlate with differences in personality (Kumari et al. 2004). With this in mind, we investigated whether individual differences in resting-state EEG activity correlate with the tendency to solve problems with insight rather than analytically (Kounios et al., 2008).

 In this study, the first step was to record a few minutes of eyes-closed resting-state activity from a group of subjects with a high-density EEG array (128-channels). These subjects did not know what they would be doing afterwards, so their brain activity could not reflect any specific expectation about the nature of the subsequent task. Then, they were given a series of anagrams to solve. (We decided to use anagrams, rather than compound remote associates, in this study in order to start to generalize our results to other types of problems.) This phase used the same insight judgment procedure we used in our previous studies with compound remote associates. On each trial, a subject viewed an anagram and when (and if) the subject derived the solution, she or he pressed a button immediately and was then prompted to verbalize the solution. Subsequently, they were prompted to indicate whether the solution had been derived with insight or analytically.

 The subjects were then divided into two groups defined by whether they solved most of the anagrams with insight or solved most of them analytically. Then, we analyzed the resting-state EEG activity of these groups separately and compared them in terms of EEG power and topography using the standard classical EEG frequency bands. We predicted two general patterns of results based on previous behavioral and neuroscience work on creativity.

 First, prior research on creativity has shown that creative individuals tend to have tonically diffuse, rather than focused, attention (Ansburg & Hill, 2003). This can be manifested as distractibility. However, such diffuse attention is thought to benefit creative individuals by allowing them to sample a greater range of stimuli in the environment. By taking in a greater range of information, this increases the likelihood that a stray stimulus will trigger a remote association that will lead to the solution to a problem. We therefore predicted greater diffuse activation of visual cortex, manifested as less alpha-band activity and less beta-band activity.

 Second, diffuse *perceptual* attention is thought to be related to diffuse *conceptual* attention, which is defined as the tendency to think in terms of remote associations. And, as discussed above, thinking in terms of remote associations is theorized to be a function of right-hemisphere activity. Therefore, we predicted greater general right-hemisphere brain activity in high-insight subjects, particularly in frontal, temporal, and parietal areas associated with semantic information processing.

 What we found was that the high-insight and high-analytical groups differed in resting-state activity in every EEG frequency band. The patterns of results were complicated, but supported our predictions. High-insight subjects showed less alpha- and beta-band activity measured over visual cortex. They also showed greater right-hemisphere activity in a number of brain areas.

 These results show that resting-state brain activity – in the absence of specific expectations or goals – biases a person toward either insight or analytical processing when subsequently given problems to solve. This means that cognitive problem-solving strategies do not arise in a “vacuum.” They are biased by preexisting patterns of brain activity which themselves are likely to result from subtle individual differences in neuroanatomy, cytoarchitectonics, or neurochemistry.

 However, what these results do *not* reveal is whether the measured individual differences in insight-related resting-state activity are stable or transient. In general, individual differences in resting-state activity are known to be fairly stable over time and genetically influenced. However, we do not yet know whether the subset of resting-state activity that is insight related is also stable and genetically loaded.

Implications and Future Directions

 Overall, this line of research shows that insight, while phenomenologically discrete, is actually the culmination of a series of brain states and processes extending over time and operating at a number of time scales ranging from milliseconds to (at least) hours. This suggests that there are a number of points in this cascade of processes that are available for external influence. Future research will investigate various possibilities for influencing these processes as a step toward developing a technology for systematically influencing cognitive style according to situational and task demands. These methods are likely to include contextual manipulation, cognitive training, pharmacology, and direct brain stimulation. It is an important goal to develop methods to maximize the likelihood that people can bring the optimal cognitive strategies to bear in a variety of critical situations so that more people react like Wag Dodge rather than like his less creative and flexible colleagues.

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