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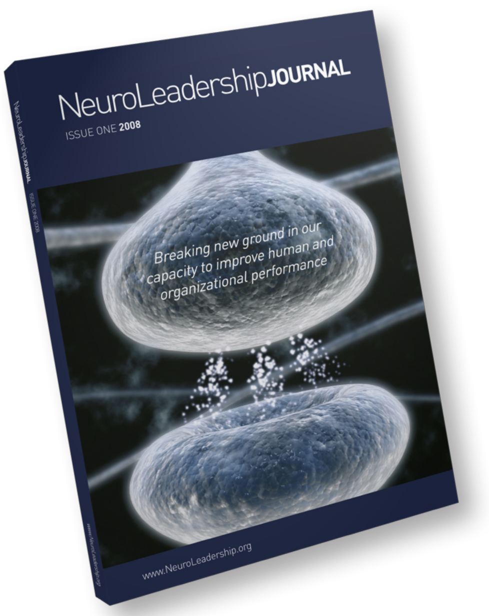

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How insight happens: learning from the brain

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This article briefly summarizes recent research investigating how the brain achieves *insight* – the sudden solution to a long-vexing problem, sudden recognition of a new idea, or sudden understanding of a complicated situation. The notion that important insights can come in a sudden *Aha!* moment is widespread and ingrained across many cultures. Since the time – legend has it – that Archimedes first shouted *"Eureka!"* ("I have found it!"), sudden insight has been colloquially described in countless ways: these are ideas that come like a bolt of lightning, out of the blue, out of thin air, or even hit like a ton of bricks. Scientific and business lore are chalk full of anecdotes describing how a single sudden insight yielded great advances – or profits.

Insight is considered an important component of creativity and contributes to many creative ideas. These days, not a week goes by without seeing a headline touting the importance of creativity and innovation. There is increasing pressure on nearly all organizations for increased creativity: for developing new products, streamlining delivery systems, optimizing managerial structure, and – not least – dealing with personnel and clients. Creating conditions conducive to insight is one way to enhance organizational creativity and leaders who are able to do this will be intrinsically valuable to their organization. Moreover, insight may be an important agent of change (i.e., for helping people change their habits and ways of thinking), due to the enhanced and perhaps distinctive way in which people remember ideas achieved through insight.

Yet, for all the attention lavished upon insight, it has, until recently, remained poorly understood by science. Two roadblocks have been the involvement of unconscious – therefore unreportable – processing leading to insight (c.f., Bowden & Beeman, 1998) and the seemingly subjective nature of defining insight (Sternberg & Davidson, 1995). In fact, some have claimed that insight does not differ from more methodical problem solving, and that it merely *feels* different (Weisberg, 1994) – although that begs the question of why some problem solutions "feel different" from others. Recent advances in brain science have opened new avenues for investigating this important topic. It is hoped that, eventually, elucidating the brain bases of insight will foster new ways to facilitate it. Already, evidence from brain science is beginning to illuminate the core processes involved in achieving insight. The goal is not to simply map brain areas involved in insight, but to use information about brain activity to inform and constrain cognitive theories of insight, and predictions about how to facilitate it.

Brain activity at the *Aha!* moment

Semantic integration

Examining brain activity for sudden insight presents several challenges. Even if we knew who the "next Einstein" was, we couldn't simply put her in a brain scanner and wait for her to have a great insight. Even if she were willing, we wouldn't learn much, because that one observation would be inadequate to interpret scientifically. Current neuroimaging techniques – ways of assessing brain activity – require averaging many observations of highly similar events, and comparing this average against that of a similar but contrasting type of event. Even many classic psychology experiments cannot be simply converted into neuroimaging experiments. These classic psychology experiments typically compared how people solved a very small number (from one to six) of insight problems (identified in earlier experiments as problems that were usually solved with some report or characteristic of insight) to a small number of analytic problems (usually solved more methodically). More observations are needed for effective neuroimaging. Furthermore, analytic problems that are of comparable difficulty to insight problems usually place a very high load on *working memory* (i.e., keeping various facts in mind while performing additional operations). Comparing these two classes of problems would undoubtedly show increased activity in working-memory brain areas during analytic solving, which would overshadow the critical operations of insight.

In the first study to isolate brain activity at the moment people solve with insight (Jung-Beeman et al., 2004), we were able to overcome these challenges by using a large set of simple word problems that can be solved either with insight, or more analytically. The problems were modeled on the Remote Associates Test (Mednick, 1962), which has been used as a test of creativity. In our version, called Compound Remote Associate (CRA) problems, people view three problem words, e.g., *storm, wave, drain.* They have to think of a solution word that can form a compound or a common two-word phrase with each of the problem words. For instance, *rainstorm* works, but *rain* doesn't fit with the others; similarly, *heat wave* works, and *drain plug* works, but neither heat nor plug fits with the other words. However, *brain* can fit with all three words (*brainstorm, brain wave, brain drain*).

After each solution (people solve about half within 30 seconds), participants pressed a button to indicate *how* they solved the problem. About 40-50% of the time, people solve these problems by methodically generating compounds for one problem word (pick the one that seems most constraining), and testing it out with the other problem words. When they succeeded this way on a problem, participants pressed a button to indicate that they solved the problem analytically, without insight. The remaining 50-60% of the time, people are thinking about the problem in one way, when suddenly a different word pops into mind, and instantly they "just know" this word fits with all three problem words. This sudden obviousness is a hallmark of insight, so when this happened, participants pressed buttons indicating they solved with insight.

While people performed this task, we measured brain activity in two ways: in one experiment with functional magnetic resonance imaging (fMRI), and in another with electroencephalography (EEG). Somewhat indirectly (through blood oxygenation changes), fMRI provides excellent information about which brain areas are more active during some events compared to during other events. The fMRI signals corresponding to the second or two preceding a solution revealed distinct patterns of brain activity corresponding to insight versus analytic solutions. Several critical brain areas were more active when people solved problems with insight than when they solved the same types of problems analytically.

In the initial study (Jung-Beeman et al. 2004), this effect was statistically reliable in only one area, and in subsequent replication (Subramaniam et al., 2009) this area remains the most robust differentiator between insight and noninsight solutions. The area identified was in the anterior temporal lobe of the right hemisphere. Importantly, this is *not an "insight area";* it is an area that, among other functions, participates in integrating semantic information – with the right hemisphere area likely integrating information that is relatively distantly related. This was exactly as predicted, given that a critical feature of insight is seeing new connections, and the answer coming as a whole – that is, already integrated.

It should be noted that fMRI provides very poor information about the timing of neural activity, so that data alone could not pinpoint decisively whether the observed activity occurred before or slightly after the participants solved the problems with insight. However, a parallel study using EEG demonstrated that the onset of the critical activity began just over 300 milliseconds prior to the response – perfect timing for the sudden (and confident) recognition of the solution (Smith & Kounios, 1996). Also, although EEG by itself does not provide incontrovertible spatial information, the location of this burst of EEG activity perfectly corresponded with that provided by fMRI. Finally, EEG also provides another dimension: the frequency of the neural activity. The right temporal activity preceding the solution was in the gamma band, a high-frequency (40Hz) activity usually associated with binding information into a coherent representation – consistent with the interpretation that it reflected the emergence into consciousness of the solution idea.

Memory

Other areas of stronger activity for insight than noninsight solutions that we reported in the initial study, and were strongly verified in a later study (Subramaniam et al., 2009), included the hippocampus, and the anterior and posterior cingulate cortex. The hippocampus is involved in both memory formation and retrieval – and past reports have suggested that insight solutions are better remembered than analytical solutions (Wills et al., 2000). Moreover, we believe that insight could be involved in reorganizing memory. A classic characteristic of solving with insight is that it requires cognitive *restructuring* – a reorganization or reinterpretation of the way one views a problem. In this way, an insight is akin to understanding a joke – usually, there is a premise, followed by a punch line that makes the listener reinterpret the joke. Yet, it is often hard to remember – or at least, retell – jokes. Why? Because it's too easy to confuse and combine the punch line with the premise. Later, we'll return to the idea that this reorganization can be a useful agent of change.

Cognitive control

Both the anterior and posterior cingulate cortex are more active as people solve problems by insight than when they solve problems without insight (Jung-Beeman et al., 2004; Subramaniam et al., 2009). These deep midline brain areas are involved in cognitive control and attention (Botvinick et al., 2004), helping people switch their focus of attention from one aspect of processing to another. It is not surprising to see some aspects of the cognitive control system engaged for insight, as people must shift their processing from one train of thought – often, being stuck on a strong but incorrect association – to another. Based only on the fact that these regions are more active at insight than at analytical solutions, the precise role of each of these regions is not entirely clear. However, a few additional pieces of information described below add to the picture.

Quiet before the brainstorm

Although the burst of gamma band activity in the right temporal lobe occurs at the moment of solution, there is another component of the EEG signal that precedes it (Jung-Beeman et al., 2004). About one second before insight solutions (and not analytical ones), there is an increase in alpha-band (10-12Hz) activity measured over posterior occipital-parietal cortex (slightly to the right side), near areas where visual information is passed to other brain areas. This posterior alpha activity persists until precisely the time the gamma band activity bursts in the right temporal lobe. What does this tell us? Alpha band activity is like brain idling, it increases at rest. When such activity occurs over the visual cortex, it is thought to reflect visual gating (Worden et al., 2001). We interpret the posterior alpha activity as quieting visual input (from the problem words), so that solvers can better detect and switch attention to fragile internal activation, which may lead them to solution. If this weak activation integrates all the relevant problem elements, it is particularly useful for solution, and will likely be experienced as an insight (the whole solution emerging into consciousness all at once).

Interestingly, the fact that visual gating is employed at that moment implies the use of cognitive control; further, it implies that some neural system detected the presence of some brain activity potentially related to (or useful for) the solution. We believe that system is the cognitive control system, and involves the anterior cingulate cortex. Importantly, this doesn't mean the anterior cingulate "knows" the answer, just that it detects some competing thought (focus of brain activity) that seems potentially relevant.

The idea that cognitive control can help an individual switch from one association (sometimes a strong, but incorrect, one) to a weak, even unconscious, one, is consistent with the longstanding idea that insight involves unconscious processing.

Insight seems quite sudden. It feels, in part, that one moment you were either not thinking of the problem or were thinking of it entirely incorrectly, and then suddenly the idea pops into your head from nowhere. Psychologists asking people to make "warmth" ratings about how close they are to solving problems have observed distinct patterns for insight versus analytic problems. When working on analytic problems, warmth ratings gradually increase until solution is achieved; for insight problems, warmth ratings remain stable (though probably not at zero), then suddenly jump at solution (Metcalfe & Weibe, 1987).

Intuition

Insight solving can lead to another type of metacognition – thinking about thinking, or in this case, about solving. Like experiencing an insight, intuition seems to involve unconscious processing. Both phenomena reflect related phases of unconscious processing; intuition, as the faint presence of widespread unconscious activation, and insight as the shift to consciousness at the Aha! moment. Just like insight, most people have experienced a moment of intuition, and we are all aware of this distinct feeling of "knowing without knowing".

Oftentimes, when people are unaware of a problem's solution and don't feel as if they're progressing toward solution (so warmth ratings don't increase), they may feel or intuit that a problem is solvable. Indeed, people can guess whether insight-like problems are solvable long before they can solve them (Bowers et al. [cite]; Bolte et al. 2003). Moreover, they may have an intuitive hunch or tip-of-the-tongue experience feeling that the solution – or a better solution path – lurks beneath consciousness. Such hunches are associated with better solving, eventually. When given CRA problems to solve and a twenty-four hour break from the problems, individuals solved more problems on Day 2 if, on Day 1, they experienced an intuitive hunch that they could (eventually) solve it. Moreover, on Day 2 participants were more likely to solve the old (unsolved Day 1 problem) with a moment of insight if they experienced an intuitive hunch related to that problem on Day 1.

Understanding which intuitions are correct compared to those that are incorrect is critical to identifying which hunches are most useful in certain situations. On average, people's intuitions have validity, but they are far from perfect. In at least some instances, correct intuitive judgments of solvability are associated with increased activity in the right superior temporal cortex (Ilg et al., 2007). Thus, intuition and insight seem to share similar regions of neural activity; moreover, the processing advantage of the right hemisphere is evident in both phenomena. Further research into differentiating valid versus invalid intuition, and into fostering the ability to discern the two, could also relate to insight; at the least, valid intuitions that a solution is near would signal opportune situations for facilitating insight (see below).

Whereas neuroimaging measures provide information about which brain and mental processes seem to be engaged, they do not provide much information about the content of those processes. However, some behavioral measures can do that. If an intuition that a solution lurks beneath consciousness is valid, then even if people fail to solve a problem, they should show priming – i.e., they should be able to process the solution word quickly if they see it. Indeed, this is the case: people read solution words faster than control words Moreover, this is especially true when the words are presented to the left visual field, so that they are initially processed in the right hemisphere – further confirmation that the right hemisphere is particularly sensitive to the types of associations on which insight solutions are built (Bowden & Beeman, 1998). In fact, this right hemisphere advantage in priming, and in speed to make solution decisions, happens only when people recognize the solutions with a sense of insight (an Aha!, or immediate recognition that the word fits for all problem words) (Bowden & Jung-Beeman, 2003).

However, keep in mind that the processing that led to solution priming remained largely unconscious, hence, participants did not solve those problems. When the insight solution does come into consciousness, it does so quickly, seems quite obvious, and the solver is very confident about it.

But what happens to allow the sudden boost from unconscious to conscious levels of processing? We suggest that the cognitive control system detects weak (unconscious) neural activity, and engages a switch of attention to the new target, bringing it into awareness. This provides a target for the facilitation of insights: variables that improve the ability to detect weak associations may improve insight solving.

Preparatory state and mood

In another experiment, we observed a remarkable precursor of insight. We examined brain activity during a preparatory period preceding each problem that people tried to solve (Kounios et al., 2006). This was a resting period, before people even knew what the next problem would be (although they knew it would be another CRA problem). We contrasted the pattern observed prior to problems that they eventually solved with insight to the same period prior to problems later solved analytically. Note that both conditions were successful, but successful in different ways.

Several brain areas were more active during insight preparation than during analytic preparation (leaving aside whether the type of preparation was intentional). These areas included temporal lobe areas on both sides of the brain, which suggests that prior to insight people were prepared to engage two types of semantic processing (Jung-Beeman, 2005): close associations (left-hemisphere semantic processing) and more remote associations (right-hemisphere semantic processing). The other brain areas involved in insight preparation were anterior and posterior cingulate cortex, suggesting that being ready to engage these components of the cognitive control system is conducive to insight. Several interpretations of this activity are possible, but again, we currently interpret the anterior cingulate cortex activation as being prepared to detect competing associations, allowing other components to direct attention towards them.

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As for the reverse comparison, in general, only visual brain areas were more active during analytic preparation than during insight preparation. This suggests that when people were prepared to pay more direct attention to the visual input rather than the chain of evoked internal associations, then they were more likely to solve analytically than with insight.

The preparatory states described above varied from trial to trial, within individuals. However, there are other factors that vary more slowly, or may be intrinsic to individuals, that could make them better able to solve with insight. For instance, we have also observed that when people have no task to perform and can simply think whatever they want, and indeed don't even know what task they will later perform, distinct patterns of resting state brain activity are associated with individuals who preferentially solve anagrams with insight compared to those who solve anagrams more analytically (Kounios et al., 2008).

At least one factor appears to directly affect the preparatory brain activity described above: mood. It has long been reported that people in a relatively positive mood, whether naturally occurring or induced experimentally, are better able to solve insight or creative problems (Isen et al., 1987; Ashby et al., 1999, for reviews). Likewise, we observed that the amount of positive mood participants reported when entering our experiment correlated with the number of CRA problems solved as well as with the degree to which they solved the problems with insight (Subramaniam et al., 2009); and, participants solved more problems, and more with insight, after watching comedy films that increased their positive mood than after neutral films.

Positive mood has also been shown to broaden attention (Gaspar & Clore, 2002), and at least one study has demonstrated both effects simultaneously (Rowe et al., 2007). Broader, less focused attention should be well-suited to detecting weak associations in the brain, enabling insight, so we predicted that the mechanism by which positive mood facilitates insight would relate to cognitive control and attention. Indeed, when we examined brain activity during the preparatory period described above, people in positive mood showed the same pattern in anterior cingulate that was associated on a trial-by-trial basis with insight preparation. That is, across all problems, the amount of activity in the anterior cingulate during the preparatory period directly correlated with positive mood (Subramaniam et al., 2009). To some extent, anxiety had the opposite effect: fewer problems solved with insight and decreased preparatory activity in the anterior cingulate.

Facilitating insight: beyond positive mood

Clearly, positive mood can facilitate insight, and therefore the aspect of problem solving, creativity and innovation that depend on insight. In reality, most problems worth solving require more than a single *Aha!* moment. They require dedicated analysis revealing the critical elements of the problem before the *Aha!* moment and often require further analysis afterward. There may be times when it is particularly useful to elicit a positive mood, as when someone is stuck but has an intuition that a solution lurks beneath consciousness. Regardless, the mechanism of positive mood's facilitation of insight may point the way to other methods. For instance, we are currently experimenting with tasks that demand particular and distinct modes of attention and observing that participating in these simple visual-spatial tasks alters (for better or worse) the ability to solve verbal problems with insight. One task that appears particularly helpful for insight is called rapid identification: pictures of objects are flashed on the screen much too quickly for normal recognition, but still possible to occasionally identify after some delay. What happens during the delay? The observer must attend not to the visual input (since the stimulus has disappeared), but to weak associations evoked by the vanished stimulus. After performing this task, participants solve more CRA problems, specifically with insight. In contrast, after engaging in a task that demands highly focused attention, they solve more problems analytically rather than with insight (Wegbreit et al., in preparation).

It could be that any behavior that encourages people to attend to their own quiet thoughts will be somewhat helpful for insight. David Rock of Results Coaching Systems (and the NeuroLeadership Journal) engages clients in problem-solving sessions during which some participants coached other individuals to consider a problem on which they are stuck. When the coaches ask questions probing about their companion's metacognition – their thoughts about their thoughts, such as *How long has this been a problem? How often does this enter your thinking?* and so on – Rock claims there is a marked increase in the number of *Aha!* moments experienced by those presenting the problems. Not that all problems are solved, but that some new insight is gained about the nature of the problem. Such techniques remain to be rigorously tested under tight control, but are consistent with some of the results observed in the problem-solving brain.

It could be that any behavior that encourages people to attend to their own quiet thoughts will be somewhat helpful for insight.

One mental behavior potentially related to insight and creativity is mind-wandering, or spontaneous thought. Mind wandering is somewhat similar to daydreaming. It occurs when an individual begins to attend to internal thoughts rather than externally driven tasks. It can happen in the absence of a task, or when a person's thoughts drift away from a task – particularly monotonous repetitive tasks. It's what happens when you are driving on the highway and after a while realize that you are thinking deeply about something else and barely attending to the road (hopefully enough to respond, if need be). Legend has it that Thomas Edison used to routinely sit in a comfortable chair and rest, allowing his mind to wander as he would perhaps be headed toward sleep. However, he would do this while balancing a spoon over a pie plate, so that should he fall asleep, the spoon would drop and the resulting clang would awaken him. He would then write down his thoughts during that period, in the belief that they were often creative. A recent neuroimaging study of mind wandering – itself a creative endeavor – revealed that spontaneous off-task thinking shared features of both "default state" brain activity and purposeful semantic processing (Christoff et al., 2004). In today's hectic environment, there may a relative paucity of time for simple, but potentially creative, mind wandering.

Conclusions

Recent research has been elucidating the brain bases of insight. The anatomical structures involved, the timing of the activity, and the type of neural activity all have implications for theories of insight and how to facilitate it. The *Aha!* moment itself seems to reflect the sudden emergence into consciousness of a representation or thought that brings together all the necessary problem elements and is likely to involve right-hemisphere semantic integration that connects distantly related concepts. This sudden emergence tends to be preceded by weak, subconscious, processing of the integrating information and usually requires a sudden shift of attention from a stronger association (or solution path). This shift, in turn, requires the engagement of cognitive control systems, particularly the anterior cingulate, and is further enhanced by a quieting or gating of sensory input to better detect the weakly active internal concept. Brain states conducive to insight can begin long before problem-solving efforts and can vary from trial to trial, be modulated by moods, and probably also differ across individuals. Behaviors that encourage attention to internal states over external stimuli seem to be beneficial for achieving an *Aha!* moment. As brain research continues to illuminate the enigma of insight, leadership research can both capitalize on this research and add to it by investigating real-world instances of insight and common practices for facilitating it.

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