Chapter

The Aha! Moment: The Science Behind Creative Insights

Wesley Carpenter

Abstract

Insight, often referred to as an "aha moment," has been defined as a sudden, conscious change in a person's representation of a stimulus, situation, event, or problem. Recent advances in neuroimaging technology and neurophysiological techniques have allowed researchers an opportunity to hone in on the neural circuitry that governs insight, a phenomenon that has been theorized about by cognitive psychologists for over a century. Studies show that insight is not a sudden flash that comes from nowhere, but in fact is the result of the unconscious mind piecing together loosely connected bits of information stemming from prior knowledge and experiences and forming novel associations among them. This conceptualization of insight naturally gives rise to comparisons between insight and creativity. Creativity, however, involves many cognitive processes, occurring in many regions of the brain and thus cannot be laterally localized as insight can. Thus, creativity is not considered synonymous with insight; however, insight can certainly result in creative solutions during creative problem solving.

Keywords: insight, Aha! moment, eureka, creativity, analytical problem solving, creative problem solving, functional fixedness

1. Introduction

Undoubtedly, we have all had them, that moment of extraordinary clarity in which the solution to a difficult problem suddenly seems to just "pop in there." Or perhaps it is a punchline to a joke that you all of a sudden get, or the perfect metaphor that suddenly comes into awareness. Where do these whiffs of inspiration come from? Do they just magically pop in there, as if given to us by some muse? Or is there perhaps a more scientific explanation? Insight, or an "Aha!" moment as it is commonly referred to, is not mysterious at all. In fact, recent advances in neuroimaging technology have made it seem less mysterious than ever. Insight has been defined as any sudden comprehension, realization, or problem solution that involves a reorganization of the elements of a person's mental representation of a stimulus, situation, or event to yield a nonobvious or nondominant interpretation. Insights may appear suddenly, but are preceded by incremental unconscious processing. Research by cognitive psychologists and cognitive neuroscientists has shown that moments of insight are merely the result of the brain making connections between weakly and strongly activated bits of information, and then bringing them to consciousness.

2. Insight versus analytical problem-solving

Some of the earliest research on insight sought to conclude whether there really was a difference between solving a problem via insight versus solving a problem via a heuristic driven type of problem solving methodology. Firstly, there are definitional differences between the two. Insight, commonly referred to as an "aha moment," has been defined as a sudden, conscious change in a person's representation of a stimulus, situation, event, or problem [1]. It should be noted that insights, while they do suddenly merge into one's stream of consciousness, are proceeded by unconscious processing to arrive at the insight. This is in contrast to analytical problem solving which involves the use of a systematic process or simply logical reasoning to arrive at a solution to a problem. It is deliberate and conscious, and often involves the use of some type of strategy which allow the individual to progress incrementally toward a solution. Because this type of methodology involves storing and manipulating information in the prefrontal cortex utilizing the individuals working memory capacity, individuals can typically fully explain the steps taken to arrive at the solution [2], whereas with insight, individuals cannot readily reconstruct the procedure followed to reach the solution. Albert Einstein summarized the unconscious nature of insight when he said, "At times I feel certain I am right while not knowing the reason" [3].

Differences between the two problem solving methods vary beyond differences in definition and accuracy of solutions, neuroimaging studies suggest that patterns of brain activity during and prior to solving by insight versus analysis are fundamentally different as well [4–6]. This suggests different cognitive strategies are being employed depending upon whether the solution arrives via insight or analytical means. Studies have shown that the brain actually predicts in advance whether the problem will be solved analytically or by insight [6, 7]. For example, Salvi et al. [8] showed that people blink and move their eyes differently prior to solving by insight versus solving analytically.

Other findings using the compound remote associates (CRA) test have provided additional support for the notion that insight processing is qualitatively different from analysis type problem solving. Compound remote associate problems are similar to items on the remote associates test developed by Mednick in 1962. Subjects must produce a solution word (e.g., sweet) that can form compounds with each of three problem words (e.g., tooth, potato, and heart). This type of test, while not considered a classic insight test, often give rise to Aha! moments. They are frequently used when studying creativity, problem solving, and insight.

Bowden and Jung-Beeman [9] presented compound remote associates test problems to participants followed by a single word that they were instructed to verbalize as quickly as possible. This known as cognitive priming. For unsolved problems, following verbalization participants indicated whether the word was the solution to the problem they had just been given. If it was, subjects had to indicate whether this realization had come to them suddenly, which would indicate insight, or incrementally, which would indicate an analytical solution strategy was employed.

Another type of cognitive priming was used to induce abstract thinking in subjects as opposed to concrete thinking by asking subjects to thinking about distant ideas (past or future), remote locations or other's perspectives versus asking subjects to think about ideas related to the here and now. According to construal level theory, increasing the psychological distance, that is, thinking about things that are increasingly far away in space or time or about people that are different from oneself tends to engage abstract thinking [10], which in turn is hypothesized to produce more creative and insightful ideas. Subjects who were primed to think in the abstract by considering ideas at far psychological distances performed better on insight related tasks whereas those primed to think concretely by considering ideas at short psychological distances did considerably better on problems requiring analysis [11].

2.1 Differences in cognitive strategies

A study by Salvi et al. [8] suggest additional evidence that there are differences between insight and analysis problem solving wherein it was revealed that solutions provided by insight were correct more often that solutions garnered by analysis. A possible explanation of this is that insights are typically all or nothing, i.e., there is no intermediate opportunity to alter one's information or solution strategy, ideas, thought processes, etc., when there is a looming deadline whereas analytical problem solving, due to its conscious nature, allows for individuals to make errors of commission, becoming fixated on irrelevant information (i.e., functional fixedness), etc., as a looming deadline approaches [7].

A pattern of errors made by subjects using either of the two methods suggests differences in cognitive strategies for problem solving via insight and analysis. They found that participants who solve predominantly by insight tend to make errors of omission (i.e., time outs) rather than errors of commission, whereas participants who tend to solve analytically make errors of commission rather than errors of omission (i.e., incorrect responses).

3. The neuroscience of insight

Recent technological advances have allowed neuroscientists to begin getting closer to understanding the complex neural underpinnings of the Aha! moment, i.e., insight. Neuroimaging studies on the insight phenomenon typically involve the use of either electroencephalography (EEG) or functional magnetic resonance imaging (fMRI), or commonly a combination of both to investigate the temporal dynamics and neural correlates of insight. Electroencephalography affords the researcher high temporal resolution which provides highly precise time measurements which are necessary to capture the rapidly changing electrical activity in the brain when subjected to stimulation. A disadvantage of EEG, however, is poor spatial resolution. Thus, functional magnetic resonance imaging is commonly used to provide high spatial resolution for precise localization of brain activity. Together these techniques are able to isolate the neural correlates of insight in both space and time.

As discussed above, the development of short compound remote associates problems readily solvable by insight by Bowden and Jung-Beeman has proved useful in neuroscientific studies as well. Early studies of insight typically posed a small number of complex problems to participants. Most participants take many minutes to solve such problems, when they are able to solve them at all. However, neuroimaging and electrophysiological methods require many trials to accurately record brain activity. Compound remote associates problems are well suited to neuroimaging and electrophysiological studies.

These types of problems afford the researcher two primary advantages. First, they can be solved via insight or through analysis. Furthermore, each problem presented, whether solved with insight or analysis, does not differ in complexity or solving duration [2, 12]. Essentially, this test controls for all confounding variables for the actual cognitive strategy used, therefore whether insight or analysis was used can be more easily identified without error. Secondly, a response utilizing either method can be given relatively quickly, thereby allowing a large number of trials per condition in a short time period [7].

As described above, each compound-remote-associates problem consists of three words (e.g., potato, tooth, heart). Participants are instructed to think of a single word that can form a compound or familiar two-word phrase with each of the three problem words (e.g., sweet can join with potato, tooth, and heart to form sweet potato, sweet tooth, and sweetheart). The instant subjects think of the word that can combine with all three, they press a button as quickly as possible. Subjects are instructed to not take any time to analyze the solution, simply press the button as soon as they become aware of the solution. They are then prompted to verbalize the solution and then to press a button to indicate whether that solution had popped into awareness suddenly (insight) or whether the solution had resulted from a more methodical hypothesis-testing approach.

When participants indicated that the solution had popped into awareness suddenly, thus indicating insight, the EEG showed a burst of high-frequency gamma waves over the right temporal lobe (just above the right ear in the right hemisphere) as shown in **Figure 1**, and the fMRI showed a corresponding change in blood flow in the medial aspect of the right anterior superior temporal gyrus (aSTG) [4]. No gamma wave activity was reported in the left hemisphere. This activity in the right hemisphere (RH) is interpreted as the sudden availability of the solution coming into consciousness, i.e., the Aha! moment.

The spatial and temporal correspondence of the EEG and fMRI signals suggests they were triggered by the same underlying neural event [13]. Activity was also reported in the bilateral hippocampus, para-hippocampal gyri and anterior and posterior cingulate cortex, but further studies suggest activity in these areas were relatively weak compared to the strong signals produced in the right anterior superior temporal gyrus. Moreover, the signal produced in the right temporal region of the brain occurred nearly the same time as when subjects realized the solution to each of the problems; the same region that is implicated in other tasks requiring semantic integration [14]. Furthermore, high frequency gamma-wave signals have been proposed to be a mechanism for assimilating and ultimately making connections among information as it emerges into consciousness [15].

Figure 2 highlights differences in EEG power just before, during and after the solution to the problem was given by the individual. The figure clearly shows

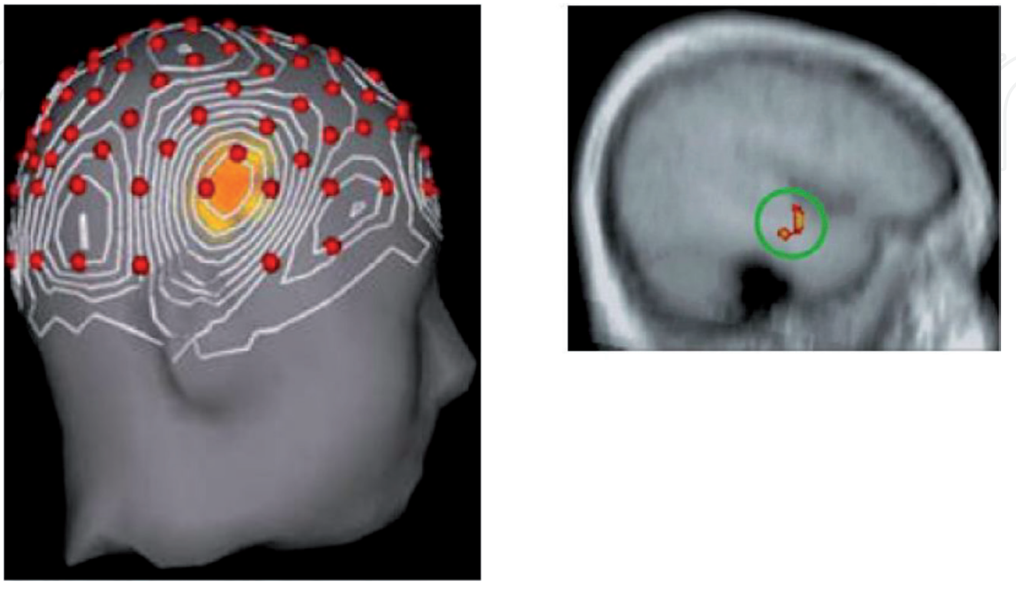

Figure 1.
The image on the left shows a topographic distribution of gamma-band activity during the insight solutions and the image on the right shows area of activation corresponding to insight effect during functional magnetic resonance imaging (fMRI). Adapted from Kounios and Beeman [13].

a distinct difference in EEG power when the participant reported a solution via insight whereas virtually no change in EEG power when a solution was arrived at via an analysis type of problem solving method. Thus, clear differences in neural activity just before a solution comes to consciousness validates distinct differences between solution by insight and solution by analysis. It should be noted that one of the advantages of problem solving via insight is that sometimes it brings nonobvious solutions to problems to conscious awareness. The anterior cingulate cortex (ACC) is thought to prepare the brain for the integration of weakly activated ideas and solutions [5]. When a problem is presented, one's attention is typically dominated by obvious solutions to a given problem, however, if there exists inconsistent or competing information, the ACC is can become activated, and thus allow more distant, weakly activated ideas to come to consciousness.

In addition to the increase in gamma wave activity, **Figure 3** shows a sudden increase in power in the alpha-band frequency occurred about 1.5 s before insight solutions, suggesting a decrease in neural activity within the right visual cortex. These effects are not attributable to emotional responses, because the neural activity preceded the solutions. Alpha waves reflect cortical deactivation or inhibition of certain brain areas [5], thus the increase in alpha waves just before solution is analogous to looking away, closing one's eyes, or looking up at the ceiling, all of

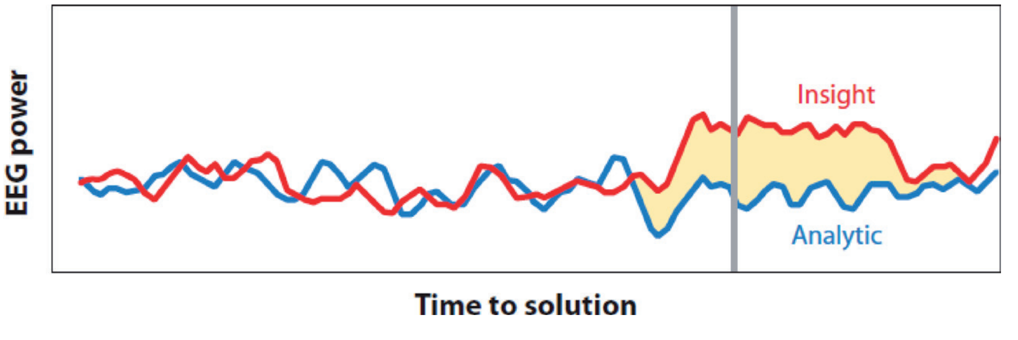

Figure 2.
Time course of insight- and analysis-related gamma-band EEG power. Adapted from Kounios and Beeman [38].

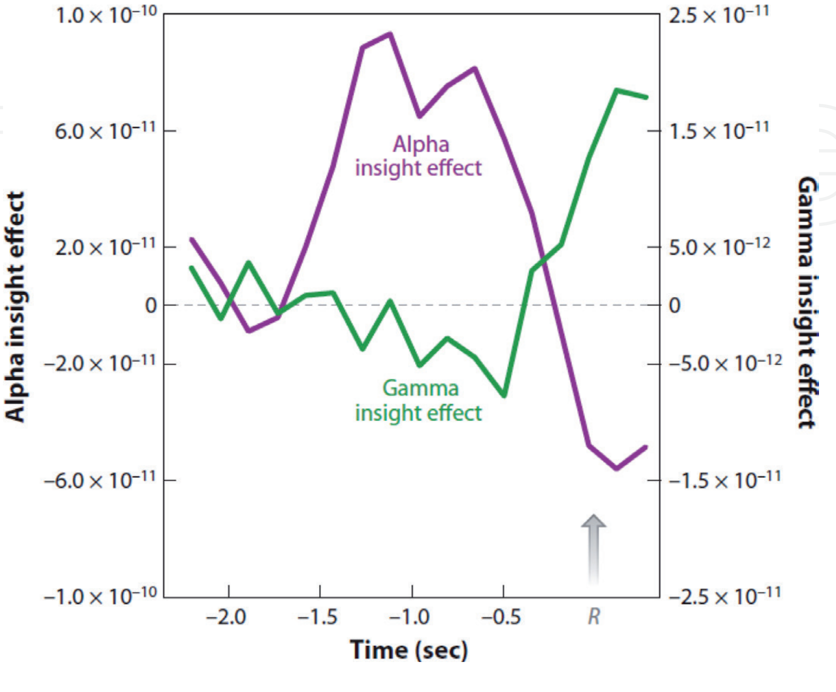

Figure 3.
Graph showing large increase of power in the alpha-band frequency just prior to increase in gamma band activity, known as the alpha insight effect. Adapted from Kounios and Beeman [38].

which are common tactics employed by individuals to minimize visual distractions when solving problems. The burst of alpha waves and then gamma waves suggest before insight solutions suggest the brain is changing the focus of its efforts to limit visual distractions thereby facilitating the integration of remote semantic elements and allowing a pathway for it to emerge into conscious awareness. This is in contrast to solutions produced via analysis which shows increased neural activity (i.e., decreased alpha-band activity) in the visual cortex. A decrease in alpha waves indicates a response to demands on one's attention, thus the decrease in alpha waves suggests subjects were focusing on the external environment while solving problems rather than making attempts to minimize distractions.

The primary take-away appears to be that a subject's neural activity during resting state, i.e., task-free state, prior to each compound remote associates problem suggest that distinct patterns of neural activity precede problems that people eventually solve by insight versus those solved by analysis. These changes in the brains resting state prior to solving insight problems suggest it is possible to predict a priori whether a subject is likely to use insight to solve a problem rather than analysis.

4. The psychology of insight

The neuroscientific view of insight allows to understand the neurological processes that underpin the moment of insight, but what exactly is insight from a cognitive psychology point of view? Indeed, Aha! moments are one of the most intriguing and unexplained processes of the human mind [16]. From a cognitive psychology perspective, attempting to place the insight phenomena into a proper theoretical framework to provide scientifically valid explanations of why the insight phenomena occurs has been difficult.

Famous American psychologist William James [17] put forth the first psychological theory of insight known as the associationist theory of insight which proposed that new ideas are combinations of existing ideas, that sudden insights are merely the result of having a lot of information in being able to make connections between fax. These connections are made during a suitable incubation period, an unguided, unconscious process whereby individuals simply take time off from the problem. A competing view of insight was put forth by the German Gestaltist Karl Duncker who was attempting to explain the psychology of insight and thus put forth proper definition of insight [18]. The Gestalt view of insight described it as "a process based on reconstructing the core of a problem, rethinking its basic assumptions and originating a new and creative solution, a process usually occurring in an unexpected and unpredictable manner" [19, 20].

The Gestalt view of insight differed in that they believed insight problems are solved suddenly and therefore no chain of connections could explain the discovery. This view suggests that insights occur while performing an analysis of the problem in which you are drawn to a potential solution, but then realize it cannot work. This is referred to as an impasse in which your mind becomes fixated on a particular solution and you therefore become incapable of exploring the problem from other angles. The solution arrives not by making incremental associations but by overcoming the fixation thus allowing a restructuring of a problem that allows you to eventually arrive at a solution. Restructuring is conceptualizing the problem differently, essentially seeing the problem in a whole new way, hence the solution is sudden and surprising. Individuals are not consciously aware of how they overcame the problem.

Other theories have been proposed to provide theoretical framework to explain insight. For example, The Progress Monitoring Theory by MacGregor et al. [21], is based on the hill-climbing idea that problem solving proceeds with the problem solver seeking to minimize the gap between the current state of the problem and the goal state. Individuals begin attempting to solve a problem by putting forth what they believe is an informed solution, which is then subsequently altered by making incremental improvements to the solution thereby getting closer and closer to the correct solution. When such incremental improvements do not result in the correct solution, the individual reaches an impasse, often likely due to the individual becoming fixated on an incorrect strategy or incomplete information. Now the individual must search for a new approach to solve the problem. This theory implies that individuals constantly monitor their own progress in order to promptly switch to a different problem-solving strategy in case the current one is not successful. This theory suggests that the Aha! moment may be achieved with an incremental approach, with constant monitoring of one's own cognitive processes as a pivotal feature, making the Aha! moment more like a conscious epiphenomenon of a general problem-solving process rather than a burst of uncommon cognitive processes [22, 23].

In contrast to the Progress Monitoring Theory, Knoblich and colleagues introduced the Representational Change Theory [24] which offered an alternative explanation of how an impasse is overcome, that is, through a reorganization of a problem's representation. Representation can be thought of as the distribution of activation across pieces of knowledge in memory [25]. This theory suggests that the problem is first represented using information or knowledge that is not relevant for the solution, hence an impasse is reached. Once this impasse is reached, the representation is altered such that relevant information becomes active and a viable solution merges into consciousness. Knoblich et al. [24, 26] suggest that the main issue of problem-solving is an individual's tendency to set unnecessary constraints through a very restricted representation of the problem, which is a function of limited, incomplete or ambiguous prior knowledge. Once the impasse is reached, by relaxing the unnecessary constraints that have been placed on the problem by deactivating the recalled knowledge linked to the problem or decomposing elements of the task by dividing it into perceptual chunks, a new representation of the problem can be reached [23, 25].

Progress Monitoring Theory and Representational Change Theory differs primarily in how one deals with an eventual impasse that impedes a solution. Bowden and Beeman have proposed another theoretical framework to explain insight by attempting to link a cognitive psychological model to actual neurological processes within particular regions of the brain. The theory proposes that insights occur when the initial representation of the problem initiates a strong semantic activation of information that allows for the generation of obvious solutions to a problem and a weak (unconscious) semantic activation of remote, alternative information important for the generation of non-obvious solutions to a problem. The weak semantic activation which is responsible for allowing remote associations to be made is thought to be produced in the right hemisphere whereas the strong semantic activation is thought to be produced in the left hemisphere [22]. Initially, solvers may be unable to take advantage of weak solution activation because it is weak, and therefore might be blocked by stronger, more focused, but misdirected semantic activations [22]. A new restructured representation of the problem emerges when integration of weakly activated information and subsequent associations made therein are reinforced, strengthened, and ultimately emerge into consciousness.

It is important to recognize that both hemispheres of the brain involve complimentary processes that work synergistically to produce a solution. Information is shared between the two hemispheres, it is the presence of this laterality that allows the solution to merge into consciousness. However, it is thought that the right hemisphere s predominantly responsible for the generation of non-obvious solutions to a given problem, i.e., creative problem solving. Psychological studies of insight suggest that the good gestalt theory is largely false. The consensus among scholars is that insight is primarily a function of previous experience and acquired knowledge [27]. Rather than a sudden restructuring, the mind seems to gradually get closer to the correct solution. And that's pretty consistent with the association theory and the Bowden and Beeman theory that creativity occurs when existing ideas combine together. The existing ideas on the new metal structure our new, they're familiar ideas and Conventions that are already in the domain and then have been internalized by the creator.

5. The relationship between insight and creativity

One of the most enduring theories of creativity is the Wallas [28] model of creativity. It begins with a preparation stage where the individual properly identifies and defines the problem, and then proceeds to gather information necessary to solve the problem. Next comes incubation which involves taking some time away from a problem to allow the unconscious mind to process the information to produce a solution. This is the state where information is assimilated, and remote associations are thought to be formed [29].

The third stage in the Wallas model is illumination, or more commonly referred to as insight because it results in the familiar Aha! experience. During this stage, a solution suddenly emerges into consciousness, light a lightbulb being turned on. This sudden illumination is still controversial however. Weisberg [30] wrote, "there seems very little reason to believe that solutions to novel problems come about in leaps of insight. At every step of the way, the process involves small movements away from what is known" (p. 50). Perhaps we only perceive it as sudden because the processing that led up to the insight is below conscious awareness [31]. Prominent creativity researcher Sawyer [27] suggests insights only seem sudden because we didn't notice the many incremental steps, or mini-insights, that immediately preceded it. He suggests rather than the familiar light bulb turning on metaphor, perhaps the tip of an iceberg or final brick in the wall is more appropriate.

The final stage was verification. At that point, the individual tests the idea or applies the solution. Although the four stages of the creative process included in the Wallas model are generally accepted to be accurate, it is generally accepted that the creative process is much more recursive than the linear Wallas model is depicted as being. It is worth noting that while other models have dissected the four stages of the Wallas model into further stages, the fundamental four of the Wallas model still remain.

With respect to the second stage of the Wallas stage model of creativity, namely incubation, one of the oldest observations in the psychology of creativity is that a creative idea is often preceded by a period of unconscious incubation [17, 32]. There is much research studying the incubation effect and its relationship with creative insight [16, 33–35]. It is generally agreed upon that there exists an incubation effect, although the exact nature of the associated unconscious processes remains uncertain. Hypotheses include mental relaxation, selective forgetting, random subconscious recombination, and spreading activation.

The relationship between insight and creativity is still a controversial one. Whether insight is a component of creativity (or a component of the creative process), simply a form of problem solving that may or may not produce a creative solution to a given problem [36], or something else entirely is as yet unanswered. Experimental and theoretical work support conflicting views regarding this question [37]. Sternberg and Davidson [16] conceptualized creativity as the ability to change existing thinking patterns, producing something that is useful, novel and generative. One cannot help but notice similarities between this conception of creativity and the generally accepted definition of insight, namely "a reorganization of the elements of a person's mental representation of a stimulus, situation or event to yield a nonobvious or nondominant interpretation" [38]. Thus, it is likely that both conceptions are correct. We know from experience that insight is not always involved in creative problem solving and therefore must not be a necessary component of it. Creative solutions can also arise through a conscious, deliberate analysis of the problem [39].

Creativity and insight have similar neurological correlates as well. Deliberate creativity that results from analysis is primarily controlled by the prefrontal cortex. However, creativity that comes as a sudden flash of insight involves three brain regions, namely the temporal, occipital, and parietal (TOP). Moreover, a prominent view of creativity is that it is based on the processing of remote or loose connections between ideas [40]. Research suggests the brain's right hemisphere is primarily responsible for the processing of remote associations and the brains left hemisphere is responsible for the processing of close or obvious associations [4]. Research suggests it is this rightward asymmetry that allows for weak activation of a broad semantic field, thus allowing for nondominant, remote associations between disparate ideas to take place. Hence the Bowden and Beeman theory seems to provide a neurological basis for Mednick's theory of creativity.

6. Conclusion

Insight is any sudden comprehension, realization, or problem solution that involves a reorganization of the elements of a person's mental representation of a stimulus, situation, or event to yield a nonobvious or nondominant interpretation. Insight is sudden, but it is preceded by incremental unconscious processing, sometimes referred to as mini-insights [27]. This unconscious processing appears to involve the integration of information contained within a weakly activated broad semantic field thus allowing remote associations of knowledge to stream into consciousness culminating in what we often refer to as an insight. It comes to consciousness suddenly, thus giving rise to the familiar Aha! moment. Such activation of remote associates naturally gives rise to comparisons to creativity, and the potential relationship between insight and creativity.

Insights are considered simply another way individuals produce creative solutions to problems. Neuroimaging studies suggest insights emanate predominantly from the right anterior superior temporal gyrus region of the brain, thus our understanding of the neural correlates involved in insight has increased considerably. It is generally accepted however, that creativity cannot be localized to a single region of the brain. Creativity appears to be highly lateralized in that several regions of the brain are active simultaneously. This makes sense, creativity involves many cognitive abilities, each of which involve many regions of the brain. Thus, creativity is not a moment of insight; however, insight can produce creativity if creativity happens to be the desired output [27]. In addition, it is worth noting that while the weak activation of a broad semantic field involved in insight is thought to be localized to the right hemisphere, thus perhaps giving rise to the popular myth that creative individuals are right-brained, there is no evidence to support such distinct brain lateralization, both hemispheres are active and contribute equally to creative problem solving.

Author details

Wesley Carpenter
The University of Akron, Akron, Ohio, USA

*Address all correspondence to: wac1@uakron.edu

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