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Is creative insight task-specific? A coordinate-based meta-analysis of neuroimaging studies on insightful problem solving

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ABSTRACT

The question of whether creative insight varies across problem types has recently come to the forefront of studies of creative cognition. In the present study, to address the nature of creative insight, the coordinate-based activation likelihood estimation (ALE) technique was utilized to individually conduct three quantitative meta-analyses of neuroimaging experiments that used the compound remote associate (CRA) task, the prototype heuristic (PH) task and the Chinese character chunk decomposition (CCD) task. These tasks were chosen because they are frequently used to uncover the neurocognitive correlates of insight. Our results demonstrated that creative insight reliably activates largely non-overlapping brain regions across task types, with the exception of some shared regions: the CRA task mainly relied on the right parahippocampal gyrus, the superior frontal gyrus and the inferior frontal gyrus; the PH task primarily depended on the right middle occipital gyrus (MOG), the bilateral superior parietal lobule/precuneus, the left inferior parietal lobule, the left lingual gyrus and the left middle frontal gyrus; and the CCD task activated a broad cerebral network consisting of most dorsolateral and medial prefrontal regions, frontoparietal regions and the right MOG. These results provide the first neural evidence of the task dependence of creative insight. The implications of these findings for resolving conflict surrounding the different theories of creative cognition and for defining insight as a set of heterogeneous processes are discussed.

1. Introduction

Creative insight, a type of creative cognition, has an important role in advancing social development and in enabling adaptation to an increasingly challenging world. Abundant evidence from historical documents and anecdotal recordings has demonstrated the importance of creative insight in scientific discoveries, technological innovations, and artistic creations as well as in an individual's success (see Dietrich and Kanso, 2010; Radel et al., 2015). As a complex and multifaceted process, creative insight has been scientifically examined for only a century since Kohler's pioneering research. With the development of neuroscientific techniques, especially the coupling of functional resonance imaging (fMRI) and traditional cognitive measures, a new approach to creative insight, namely, brain-based insight, is being characterized. This approach has greatly expanded understanding of the essence of creative insight by contributing new knowledge of the neural and brain correlates that underlie the creative process and by offering strategies to facilitate insight via evidence-based brain stimulation. However, some key theoretical problems remain. One important problem currently under debate is whether creative insight is task-specific or task-independent. This question is rooted in heated controversy concerning the domain-general and domain-specific theories of creative cognition (Chen et al., 2006; Dow and Mayer, 2004; Reiter-Palmon et al., 2009).

1.1. Domain-general and domain-specific hypotheses of insight

Insight is ambiguous due to its suddenness, directness and continuousness (e.g., Epstein et al., 1984). The psychological nature of creative insight is both of great interest and highly debated. Sternberg and Davidson published a landmark book, *The Nature of Insight*, in which creative insight was examined using different influential approaches that were divided into two categories: domain-general and domain-specific. According to domain-general theory, "insight problems are thought of as a single class of problems that all require the same general problem-solving strategy"

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(Dow and Mayer, 2004). As a result, creative insights underlying the successful solution of these problems are very similar and do not have distinct cognitive mechanisms (recruiting different cognitive skills or subprocesses) or neural bases (do not activate the same brain regions and connections). In contrast, domain-specific theory argues that "insight problems can be broken down into coherent subcategories such as verbal, mathematical, and spatial insight problems, each requiring a different type of problem-solving strategy" (Dow and Mayer, 2004), which suggests that the cognitive or neural underpinnings of creative insight are modulated by domain and even cognitive tasks. In other words, insight might vary depending on the different processes needed to solve a problem.

Considerable evidence concerning differences in creative thinking (Kaufman and Baer, 2005; Plucker and Zabelina, 2009) and insight (Dow and Mayer, 2004; Weisberg, 1995; Cunningham et al., 2009), particularly regarding task performance in different domains and the origins and causes of such differences, has been presented. To address the issue of domain specificity, especially the task-independence of creativity, Reiter-Palmon et al. (2009) required participants to solve one of three realistic creative problems that differed in terms of their complexity, involvement, and problem-based efficacy. They observed that the participants' creativity was influenced by the type of problem solved (problem type accounted for approximately 4–12% of the variance after the potential impact of individual ability was excluded) as well as by the measure of creativity used to assess the solution, which suggests that not all real-world creative problems are equivalent and emphasizes the importance of how problem solvers respond to different creative thinking tasks. Similarly, Dow and Mayer (2004) directly examined the training effect of task type on insight problem solving and observed that the successful solution of different insight problems depended on distinct cognitive strategies or abilities. Specifically, they found that solutions to verbal insight problems mainly relied on the definition and analysis of the terms included in a problem; solutions to mathematical insight problems primarily depended on a novel approach to numbers; and solutions to spatial insight problems principally depended on the removal of self-imposed constraints. In the study, 158 participants were required to complete a series of measures that tested motivational and personality traits as well as intellectual abilities in addition to three creative thinking tasks, which involved artistic, verbal and mathematical domains, with different instructions. The results showed that with the exception of one intellectual factor that was linked with the domain-specific component of mathematical creativity under the explicit "be creative" instruction condition, all of the other measures and cognitive tasks were associated with or relied on domain-general components of creativity, providing strong evidence of domain generality and little evidence of domain specificity (Chen et al., 2006). Therefore, whether creative insight is a domain-general process that transcends specific domains or tasks (i.e., task-general or task-independent) or encompasses a range of domain-specific processes that vary from domain to domain or from task to task (i.e., task-specific or task-dependent) remains an open question that is worthy of further research.

1.2. Three task types commonly used to explore insight

Most brain imaging studies concerning creative insight have found that brain-based insight can be investigated and examined through many different tasks. In addition to the widely used compound remote associate (CRA) problems, the prototype-heuristic (PH) task, the riddle-guessing task (e.g., Mai et al., 2004), the degraded picture recognition task (e.g., Ludmer et al., 2011), the number reduction task (NRT; e.g., Darsaud et al., 2011), the classical insight problems solving task (e.g., the Matchstick problem; Goel and Vartanian, 2005), the chunk decomposition (CD) tasks,[1] and the magic demystifying task (Danek et al., 2013) have also been used to investigate cognition, especially the neural mechanisms underlying creative insight. Due to their domain characteristics and extensive use, this work focused on three types of task[2]: the CRA task, the PH task and the CD tasks. The following section will provide a brief introduction to these three tasks.

1.2.1. The CRA task

The CRA task, which was created by Bowden and Jung-Beeman (1998, 2003), is a variant of the remote associates task (RAT) developed by Mednick (1962). The broad utility of the CRA task in neuroscience studies of creative insight was highlighted by Jung-Beeman et al. (2004), although this task was already being used to determine the behavioral and psychological correlates of creative insight prior to this publication. This task involves a set of three words, for which participants are required to identify a solution word that can individually form a compound word or phrase with each of the three given words. For example, if the three problem words "tree," "sauce," and "pine" are presented, the participants must identify a common word, such as "apple," that can be matched with each of them, forming "apple tree," "applesauce," and "pineapple". In general, the CRA task has at least two main advantages. First, because the problems associated with the task can be solved in a relatively short period of time, many trials can be attempted in a single experimental session. Second, this task is easier to administer than other classical insight problems, which allows the exclusion of as many extraneous variables as possible (Bowden and Jung-Beeman, 2003). These advantages are responsible for the extensive utilization of the task in studies of insight problem solving, creative thinking (e.g., Lee and Therriault, 2013), and associative thought (e.g., Razumnikova, 2007). The CRA task is considered a suitable tool for measuring convergent thought (Chermahini et al., 2012; Cerruti and Schlaug, 2009) and creative insight (Razumnikova, 2007) and is not only implemented in English speaking countries, having also been translated into Russian (Razumnikova, 2007), Dutch (Chermahini et al., 2012), German, Hebrew, Japanese, and Jamaican versions (Bowden and Jung-Beeman, 2003; Shen et al., 2016). Thus, this task can be applied for behavioral and neuroscientific studies across a range of contexts.

1.2.2. The CD tasks

Every stimulus can be considered a "chunk" or a portion of a chunk. When an individual encounters an unfamiliar task, he or she tries their best to familiarize themself by automatically recognizing instances of chunks in the environment; however, in most cases, the problem solver does not know which previously acquired chunks are relevant for the solution. The term "chunk decomposition" comes from representation restructuring theory (RCT; Ohlsson, 1992; Knoblich et al., 1999). RCT proposes that successful insight can be achieved through constraint relaxations or CD, which destructs familiar patterns into elements (e.g., strokes or radicals; see Luo and Knoblich, 2007, for details) that can be regrouped in another meaningful way. In simple terms, CD is the opposite of chunking. As a specific form of insightful thinking, CD has been shown to be linked with special perceptual, linguistic, and executive processes distinct from ordinary modes of thinking (Huang et al., 2015).

Knoblich et al. (1999) first introduced the term CD in empirical studies of insight and defined CD sub-processes underlying matchstick arithmetic problems involving Roman numerals. As a logographic language system, Chinese characters are ideal cases of perceptual chunks. Specifically, Chinese characters are composed of (nonsensical)

[1] There may be some differences between, for example, matchstick algebra (with mathematical processes) and logographic character decomposition (without any mathematical process). However, they involve a common process (CD), and it may be more reasonable to call them CD tasks (plural) due to the above differences

[2] The three insight tasks were chosen as the targets of this work for the following reasons: First, these tasks are the most commonly used in neuroimaging studies of spontaneous insight; therefore, a sufficient number of studies was available to generate reliable results for the present meta-analyses. Second, the three tasks are the most commonly used insight tasks and involve more than one well-defined domain.