

## RESEARCH ARTICLE

# Uncovering neural distinctions and commodities between two creativity subsets: A meta-analysis of fMRI studies in divergent thinking and insight using activation likelihood estimation

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## Abstract

The dual-process theory that two different systems of thought coexist in creative thinking has attracted considerable attention. In the field of creative thinking, divergent thinking (DT) is the ability to produce multiple solutions to open-ended problems in a short time. It is mainly considered an associative and fast process. Meanwhile, insight, the new and unexpected comprehension of close-ended problems, is frequently marked as a deliberate and time-consuming thinking process requiring concentrated effort. Previous research has been dedicated to revealing their separate neural mechanisms, while few studies have compared their differences and similarities at the brain level. Therefore, the current study applied Activation Likelihood Estimation to decipher common and distinctive neural pathways that potentially underlie DT and insight. We selected 27 DT studies and 30 insight studies for retrospective meta-analyses. Initially, two single analyses with follow-up contrast and conjunction analyses were performed. The single analyses showed that DT mainly involved the inferior parietal lobe (IPL), cuneus, and middle frontal gyrus (MFG), while the precentral gyrus, inferior frontal gyrus (IFG), parahippocampal gyrus (PG), amygdala (AMG), and superior parietal lobe were engaged in insight. Compared to insight, DT mainly led to greater activation in the IPL, the crucial part of the default mode network. However, insight caused more significant activation in regions related to executive control functions and emotional responses, such as the IFG, MFG, PG, and AMG. Notably, the conjunction analysis detected no overlapped areas between

**Abbreviations:** AMG, amygdala; AG, angular gyrus; ACC, anterior cingulate cortex; BA, Brodmann area; CG, cingulate gyrus; CUN, Cuneus; DMN, default mode network; DT, divergent thinking; DLPFC, dorsolateral prefrontal cortex; ECN, executive control network; FG, fusiform gyrus; HG, hippocampal gyrus; IFG, inferior frontal gyrus; IPL, inferior parietal lobe; MedFG, medial frontal gyrus; MTL, medial temporal lobe; MFG, middle frontal gyrus; MTG, middle temporal gyrus; PG, parahippocampal gyrus; PoCG, postcentral gyrus; PCC, posterior cingulate cortex; PreCG, precentral gyrus; PCUN, precunes; PFC, prefrontal cortex; SN, salient network; SFG, superior frontal gyrus; STG, superior temporal gyrus; SMG, supramarginal gyrus; VLPFC, ventrolateral prefrontal cortex.

Changyi Kuang and Jun Chen contributed equally to this study.

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DT and insight. These neural findings implicate that various neurocognitive circuits may support DT and insight.

#### KEYWORDS

ALE, divergent thinking, fMRI, insight, meta-analysis, neural mechanism

## 1 | INTRODUCTION

Divergent thinking (DT) and insight have drawn researchers' attention among creative subfields. Guilford (1967) referred to DT as the ability to produce multiple solutions to open-ended problems (Benedek et al., 2011; Zhang et al., 2020) and is deemed an associative process (Cropley, 2006; Gabora, 2010). Forming novel associations and then delivering multi-dimensional answers within a short period is a characteristic of DT. And turning to insight, it is always pervasive in finding creative solutions to difficult problem-solving processes. Insight usually refers to an abrupt, unexpected, and novel comprehension of the innovative and correct answer when tackling problematic situations. Being accompanied by positive emotional feedback, insight is also interpreted as the Aha/Eureka moment (Jung-Beeman et al., 2004; Shen, Yuan, Liu, & Luo, 2016; Tik et al., 2018). A sure and concrete response usually comes after such effortful thinking (Jung-Beeman et al., 2004; Kounios & Beeman, 2014). Recently, the dual-process theory of thought between associative process (also called System 1, intuition, and fast thinking) and hypothetical process (also called System 2, deliberation, and slow thinking) has been exploited to better understand human thought. System 1, or fast thinking, operates autonomously, rapidly, and effortlessly, while System 2, or slow thinking, is controlled, slow-paced, and effortful (Evans, 2003; Gronchi & Giovannelli, 2018; Kahneman, 2011). Given these characteristics, previous studies have introduced two cognitive systems to interpret DT and insight's processing patterns. It is understood that DT is mainly marked as associative, autonomous, and effortless, while the dominant features of insight are always regarded as effortful and time-consuming since this process demands concentrated effort to overcome mental fixedness (Lin et al., 2011; Lin & Lien, 2013). Previously, researchers assumed that the two cognitive systems might coexist and interact in DT and insight (Barr et al., 2014; Sowden et al., 2015). However, the specific supportive roles of the two systems toward DT and insight are still poorly defined. Furthermore, few studies have directly compared the differences and similarities at the brain level between DT and insight, and few data could likely provide new neural evidence of the two systems' roles in DT and insight.

With the development of cognitive neuroscience, researchers have found that areas like the inferior frontal gyrus (IFG), middle frontal gyrus (MFG), inferior parietal lobe (IPL), supramarginal gyrus (SFG), anterior cingulate cortex (ACC), and precuneus (PCUN) were reported as being key brain areas in DT studies (Benedek, Beaty, et al., 2014; Cogdell-Brooke et al., 2020; Fink et al., 2009; Gonen-Yaacovi et al., 2013; Howard-Jones et al., 2005). When in insight, the frontal-parietal areas (e.g., IFG, MFG, and IPL), anterior and posterior

cingulate cortex (ACC and PCC), hippocampal gyrus (HG), and the amygdala (AMG) were frequently detected (Anderson et al., 2009; Kounios et al., 2006; Lin et al., 2020; Luo et al., 2004a; Luo & Niki, 2003; Shen et al., 2018; Shen, Yuan, Liu, Zhang, et al., 2016). These findings raised whether a common or a specific activation pattern exists between DT and insight. But, in retrospect to previous meta-analyses (i.e., Boccia et al., 2015; Cogdell-Brooke et al., 2020; Shen et al., 2018; Shen, Yuan, Liu, Zhang, et al., 2016; Wu et al., 2016), they have little access to peculiar brain activation underlying DT or insight since they tended to integrate onefold fMRI studies within only one creative subset. These existing explorations cannot tell the common and specific cognitive systems mainly resided in DT or insight, restricted by a single analysis method. Thus, carrying out further contrast and conjunction analyses becomes necessary. This analytical approach could make cross-sectional comparisons and specialize in brain activation under different creative processes.

### 1.1 | Divergent thinking

Research has shown that producing substantial manifold creative thought in a short time signaled DT. It is hypothesized that a chain of constructive components may constitute it, such as long-term memory retrieval (Avitia & Kaufman, 2014; Silvia et al., 2013), passive conceptual expansion (Abraham et al., 2012; Sowden et al., 2015), and remote associate combination (Benedek, Franz, et al., 2012; Mednick, 1962). This broad retrieval ability often lays a foundation for subsequent automatic processes (Forthmann et al., 2019). Additionally, better creative DT performance is sometimes correlated with a defocused attention state (Vartanian et al., 2007), and individuals may instantly produce a novel idea in DT. The whole process was regarded as associative and spontaneous, with autonomy and intuition (Benedek & Jauk, 2018; Gabora, 2010), reflecting a key property of fast thinking mentioned in the dual-process model (Evans, 2003).

A handful of experimental paradigms have been frequently applied in studying DT, including the alternative use task (AUT; Beaty & Mathias, 2017), verb generation task (VGT; Seger et al., 2000), novel metaphor task (NMT; Benedek, Beaty, et al., 2014), and creative story generation (CSG; Howard-Jones et al., 2005). These flexible assignments productively provoke creative thoughts and encourage participants to generate multiple ideas. In particular, AUT, pioneered by Guilford, represents the classical method of assessing DT. Hence, participants are offered everyday items (e.g., shoes, brick) with an accompanying request to suggest as many alternatives uses as possible. Trained experts then perform a standardized after-

evaluation, scoring indexes of flexibility (i.e., variabilities of creative ideas), fluency (i.e., number of creative ideas), and originality (i.e., the infrequency of creative ideas; Heinonen et al., 2016; Sternberg & Lubart, 1996). Many recent experiments have focused on investigating the neural mechanisms behind DT (Abraham et al., 2012; Aziz-Zadeh et al., 2013; Benedek et al., 2020; Benedek & Fink, 2019). These studies implicated that the prefrontal cortex (PFC), parietal lobe, and cingulate gyrus (CG) play key roles in various types of DT.

The prefrontal brain area, including the lateral (i.e., ventrolateral and dorsolateral prefrontal cortex) and the medial PFC, was determined to be task-switcher in DT. This area of the brain has been associated with the generation of original thought that require cognitive flexibility, such as that seen in the selective recollection of associates with long semantic distance (Beatty & Silvia, 2013; Wu et al., 2015), the inhibition of unwanted information (Aron et al., 2004; Munakata et al., 2011), and flexible conceptual transformation (Abraham et al., 2018; Gonen-Yaacovi et al., 2013; Wang et al., 2019); which all support DT. Additionally, close relationships were established between lateral PFC activity and working memory (WM; Nee et al., 2013; Wagner et al., 2001), whose retrieval and manipulation are essential for DT (Goel & Vartanian, 2005; Vartanian et al., 2013). Specifically, the dorsal prefrontal cortex (DLPFC) may assist in building and organizing associations among related information maintained in the WM (Blumenfeld & Ranganath, 2016), and the ventrolateral prefrontal cortex (VLPFC) may respond to semantic retrieval and relevant representation selection in the WM (Badre & Wagner, 2007; Curtis & D'Esposito, 2003). The medial PFC effectively manages active-maintained information and integrates numerous conceptual relations from the WM (Cairo et al., 2004). The medial PFC also facilitates the production of creative thought, whose increased resting-state functional connectivity with the middle temporal gyrus has been positively related to divergent thinking (Wei et al., 2014). Accordingly, medial PFC might be responsible for the metacognitive ability that requires flexible self-regulated information in DT.

Many studies have assessed the parietal lobe's contribution to DT. There is neural evidence that the inferior parietal lobe (IPL) may contribute to the production of original ideas (Benedek & Jauk, 2018; Boccia et al., 2015) and episodic memory retrieval (Benedek, Beatty, et al., 2014; Benedek, Jauk, et al., 2014). Interestingly, the stronger IPL activity was observed in DT (especially the AUT task) rather than a low creative state. Further research showed that subregions of the IPL [i.e., supramarginal gyrus (SMG) and angular gyrus (AG)] activated in the answer generation stage of the AUT (Subramaniam et al., 2012; Sun et al., 2016). Additionally, tool manipulation has been highlighted as another role of IPL. Tool manipulation refers to the manipulation of everyday objects to discover unconventional uses. This observation during AUT has been noted by several studies (Badre & Wagner, 2007; Cogdell-Brooke et al., 2020; Ishibashi et al., 2011). Finally, the distributed activation of the superior parietal lobe (SPL) was observed in some creative DT studies, and the cuneus (CUN) is hypothesized to have a key role in semantic retrieval during creative, verbal, problem-solving tasks (Beatty & Mathias, 2017; Chen et al., 2015).

Additionally, both the anterior cingulate cortex (ACC) and posterior cingulate cortex (PCC) are often identified as important brain areas in DT studies (Fink et al., 2009; Howard-Jones et al., 2005; Wu et al., 2015). Both areas had significant activation when completing the AUT (Kleibeuken et al., 2013). Similarly, noticeable signal changes of the ACC emerged in a VGT that dropped a hint to encourage participants to think creatively (Green et al., 2014). ACC activity could predict individual originality scores (Ellamil et al., 2012). Previous studies have shown that the PCC possibly mediated the construction of new associations by weakening the impact of a conventional thinking mindset that participated in memory retrieval success (Mayseless et al., 2015).

## 1.2 | Insight

Insight happens in problem-solving situations with mental bottlenecks (Sprugnoli et al., 2017). To overcome this barrier, people may have to monitor cognitive conflicts (Kounios & Beeman, 2009), break the unwarranted fixedness (Luo & Niki, 2003), and restructure existing representations (Weisberg, 2013). Notably, feelings of successful insight often trigger strong positive emotional feedback and are characterized by a mixture of certainty, ease, and delight. Such feelings are also clarified as the Aha/Eureka moment (Jung-Beeman et al., 2004; Shen, Yuan, Liu, & Luo, 2016; Tik et al., 2018). This moment means a transition from being completely puzzled to suddenly grasping the conscious availability of solutions (Kounios & Beeman, 2009). As insight is a deliberate and time-consuming process, it is understood that it requires concentrated effort, admitted as slow thinking. This property is similar to the controlled process mentioned in the dual-process model (Evans, 2003). Assessments such as the compound remote associates (CRA) task (Kizilirmak et al., 2019; Subramaniam et al., 2009), character chunk decomposition (CCD) task (Lin et al., 2020; Wu et al., 2013), Chinese logogriphs solving (CLS) task (Qiu et al., 2010; Tian et al., 2011), and heuristic prototype (HP) problem-solving (Tong et al., 2013; Zhang et al., 2014) have been used to investigate insight. These studies show wide-ranging cerebral cortex activation across the frontal, parietal, temporal, and occipital lobes (Boccia et al., 2015). For instance, the lateral prefrontal regions (e.g., IFG, MFG), ACC, the medial temporal lobe (MTL), the AMG, and the fusiform gyrus (FG) were found to be associated with the insight process (Cartwright et al., 2004; Mai et al., 2004; Shen et al., 2017).

Several studies have advocated that the lateral PFC, mostly relying on IFG and MFG, is actively engaged during problem situations that encourage insight (Anderson et al., 2009; Gonen-Yaacovi et al., 2013; Lin et al., 2020). These key nodes were active for executive functions across several problematic situations, such as breaking mental sets (e.g., CCD tasks and riddles-solving), forming novel associations (Luo et al., 2006; Qiu et al., 2010), and cognitive control (Brass et al., 2005; Derrfuss et al., 2005). Both regions have been reported to play vital roles in cognitive inhibition toward prepotent conceptual knowledge (Ivancovsky et al., 2018; Lin et al., 2018). However, they were not only limited to that situation. Previously, the IFG and MFG

have been associated with semantic control processing in insight (Binder et al., 2009). The MFG promoted the generation of candidate semantic associations retained in the WM (Woodward et al., 2006). Furthermore, the IFG gave support to selecting distant but targeted conceptual semantic information and was able to then flexibly restructure ordinary representation in insight (Becker et al., 2019a).

Similarly, some studies have highlighted that the ACC monitored cognitive conflict (Liotti et al., 2000; Sprugnoli et al., 2017) and broke fixed mindsets in insight (Mai et al., 2004). The ACC's activity was observed to increase in participants making "partial errors"; partial errors refer to participants whose answers were initially wrong but were then self-corrected (Carter et al., 2000). Luo et al. (2004b) confirmed the role of ACC in the early warning system and found that it was activated when tackling more challenging puzzles under insightful conditions. The ACC's contribution toward cognitive control aims to overcome prepotent responses (Botvinick et al., 2001; MacDonald et al., 2000). Alternatively, it also explained incongruent information signaling (Botvinick et al., 2001) and assisted attention reorientation (Milham et al., 2003). These functions might reflect the ACC's contribution to solving insight-related problems. In particular, the ACC may suppress misleading thoughts and then shift attention to nonprepotent associations, thus allowing for the assessment of possible alternative solutions. Moreover, previous work has shown that the ACC is active during the preparation stage of insight (without obvious physical occurrences of conflict; Kounios et al., 2006; Shen et al., 2018). Together, these lines of evidence suggest that the ACC may act as a mental switch interpreted as an AHA reaction (Luo et al., 2004b).

Aside from the ACC, the medial temporal lobe (MTL) may also be a significant contributor to insight. Its critical subregions, such as the hippocampal gyrus (HG) and the parahippocampal gyrus (PG), have been closely related to insightful events (Shen et al., 2017; Squire et al., 2004). The MTL was sensitive to the recognition of novel association. For example, Hunkin et al. (2002) reported enhanced MTL activation when generating original sentences with offered word triplets rather than just repeating them. Furthermore, the role of PG during insight has been gaining interest within the MTL. In 2009, in a review by van Strien et al. (2009), the authors reported that the parahippocampal-hippocampal network was involved in memory formation (i.e., processing detailed information) and temporal dynamics (i.e., accelerating information transfer). It is understood that the HG assists in coupling internal representations with external clues, forming new associations but, more significantly, providing the capacity for self-correction during conflict situations (Redish, 2001). Thus, the HG will likely improve the error correction rate and break the fixedness impasse in insight (Luo & Niki, 2003). Distinguished from the hippocampal cortices, the PG is acknowledged as having a fundamental role in information retrieval from WM as well as forming effective associations in insight (Wang et al., 2009). It has been shown that emotional stimuli can infrequently catalyze the PG's activity. For instance, Smith et al. (2004) reported that encoding positive valence pictures instead of neutral ones led to PG's activation. Considering these findings, the hippocampus and its para-area probably contribute to insight occurrence.

Several studies have discussed the amygdala's (AMG) contribution to insight. Evidence has been shown that the AMG is the source of affective reactions that appear in insight, including happiness, ease, and certainty (Kounios et al., 2006; Shen, Yuan, Liu, Zhang, et al., 2016; Tik et al., 2018). Kizilirmak et al. (2016) reported that the activation of AMG potentially reflected a positive emotional response toward sudden comprehension during insight solutions. This phenomenon might showcase the feeling of being convinced by correct, clear, and understandable answers. Additionally, the AMG is dedicated to contextual novelty detection (Blackford et al., 2009). For example, Yu et al. (2019) employed metaphorical expressions concerning mental distress problems to induce self-generated insight. Those authors observed evident activity in the bilateral hippocampus and the AMG when the participants understood the therapeutic metaphorical sentences with novel contextual meanings. Other active clusters that have been identified in insightful problem-solving include the fusiform gyrus (FG), middle temporal gyrus (MTG), and the superior temporal gyrus (STG). Generally, the FG was involved in forming original associations and integrating representations within the insight process (Shen et al., 2017; Zhang et al., 2011). In addition, the MTG has been widely associated with semantic processing and semantic control (Abraham, 2014; Zhao et al., 2013), while the STG mainly is responsible for improving the rate of available associations in insight (Jung-Beeman et al., 2004; Shen et al., 2017).

### 1.3 | Dual-process perspective about DT and insight

From fMRI evidence, it is recognized that several similar regions (e.g., the frontal area, the cingulate, and the parietal area) and intellectual processes are involved in the creative process. The core ability to construct remote associations and combine concepts with weak relations is commonplace across DT and Insight (Benedek, Könen, et al., 2012). However, the variabilities between DT and insight are rather significant. First, DT is useful for solving open-ended problems and managing the creative flow of ideas that can arise from various directions and flood the mind. In contrast, insight is useful for forming concrete solutions to resolve closed-ended and unidirectional problems. Second, DT usually operates effortlessly, autonomously, and productively. It is stable and characterized by a phenomenal output of original thoughts. In contrast, insightful thoughts are time-consuming and effortful before the solution-verification stage. These two creative cognitions may likely differ in memory, attention, and cognitive control (Benedek & Fink, 2019). Lin and Lien (2013) have investigated the working memory between DT and insight. Those authors applied a dual-task paradigm, meaning subjects faced the dilemma of allocating sufficient WM resources to two competing tasks simultaneously. Specifically, subjects were randomly appointed to the DT task (i.e., the verbal subset of "The Chinese Version of Creative Thinking Test") or insight problem-solving task (i.e., the "2-4-6 Task" where subjects had to discover the predetermined rule of the given numerical triples). At the same time, subjects must also finish a compulsory number-

counting task (i.e., read out loud serial consecutive integers from 1000 to 1005) whatever creative task was assigned. They found that subjects' creative performance was enhanced in DT while hindered in insight upon WM load manipulation. These lines of evidence have inspired us to give a further reflection on whether DT and insight were equipped with exclusive processing systems or not.

Recently, scientists have advocated for the dual-process theory of thought between an associative process (also called System 1, intuition, and fast thinking) and a hypothetical process (also called System 2, deliberation and slow thinking). Fast-thinking (or System 1) is understood to be associatory and self-governed. It can rapidly sort out information without limitation of capacity. Parallel associations could be created and posted in the consciousness. In contrast, slow thinking (or System 2) is understood to be thoughtful and sequential. It slowly operates on symbolic systems with the help of mental efforts such as those observed in deduction and rationality (Slovan, 1996). System 2 cognition is also supposed to facilitate hypothetical thinking, abstract comprehension, and responsiveness to executive control. Previous studies have speculated that fast and slow thinking collaborate and compete mentally and have proposed that the dominance of each mode of thinking depends on ill-defined or well-defined events to be solved (Allen & Thomas, 2011; Evans, 2003; Evans & Stanovich, 2013; Sowden et al., 2015; Stanovich & West, 2000). Enlightened by this theoretical model, Lin et al. (2011) and Barr et al. (2014) have conducted verification through behavioral procedures and speculated that creativeness might be affected by the engagement of these two thinking modes.

Given the characteristics of DT and insight, researchers deduced that fast thinking might dominate DT, while slow thinking may contribute to insightful problem-solving (Lin & Lien, 2013). However, few studies have provided neuroscientific demonstrations comparing the differences and similarities between DT and insight. Previous studies have mainly focused on investigating the neural correlates of DT or insight, respectively. Therefore, we aimed to uncover unique and common neuroscientific mechanisms that may exist between DT and insight using the activation likelihood estimation (ALE) meta-analytical method. Specifically, single analyses were performed to confirm coherent brain activation during DT and insightful situations. More importantly, contrast and conjunction analyses were conducted to further identify whether areas of neural activation were overlapped or unique in DT and insight. Previous meta-analyses drew unidimensional conclusions and thus cannot tell which cognitive system is mainly responsible for processing in DT or insight. Some studies have suggested that nodes from both the DMN and the cognitive control network might offer coupling support to DT and insight (Beatty et al., 2015, 2016; Danek & Flanagan, 2019; Jauk, 2019; Ogawa et al., 2018; Vartanian et al., 2018), but the exact involvement and predominance remain imprecise. The contrast and conjunction analysis could help answer these unsolved problems in DT and insight. We speculated that DT mainly involves key cerebral regions of the DMN (i.e., medial prefrontal areas, the parietal lobe, and the cuneus), which are always activated in conditions of low cognitive load and automatic processing. Meanwhile, areas like prefrontal cortices and the

amygdala-hippocampal networks closely related to cognitive control and emotion processing might be responsible for activity during insight. Therefore, by interpreting these two creativity subsets, this study aimed to offer new neural evidence for the dual-processes theory.

## 2 | MATERIALS AND METHODS

### 2.1 | Literature search and selection

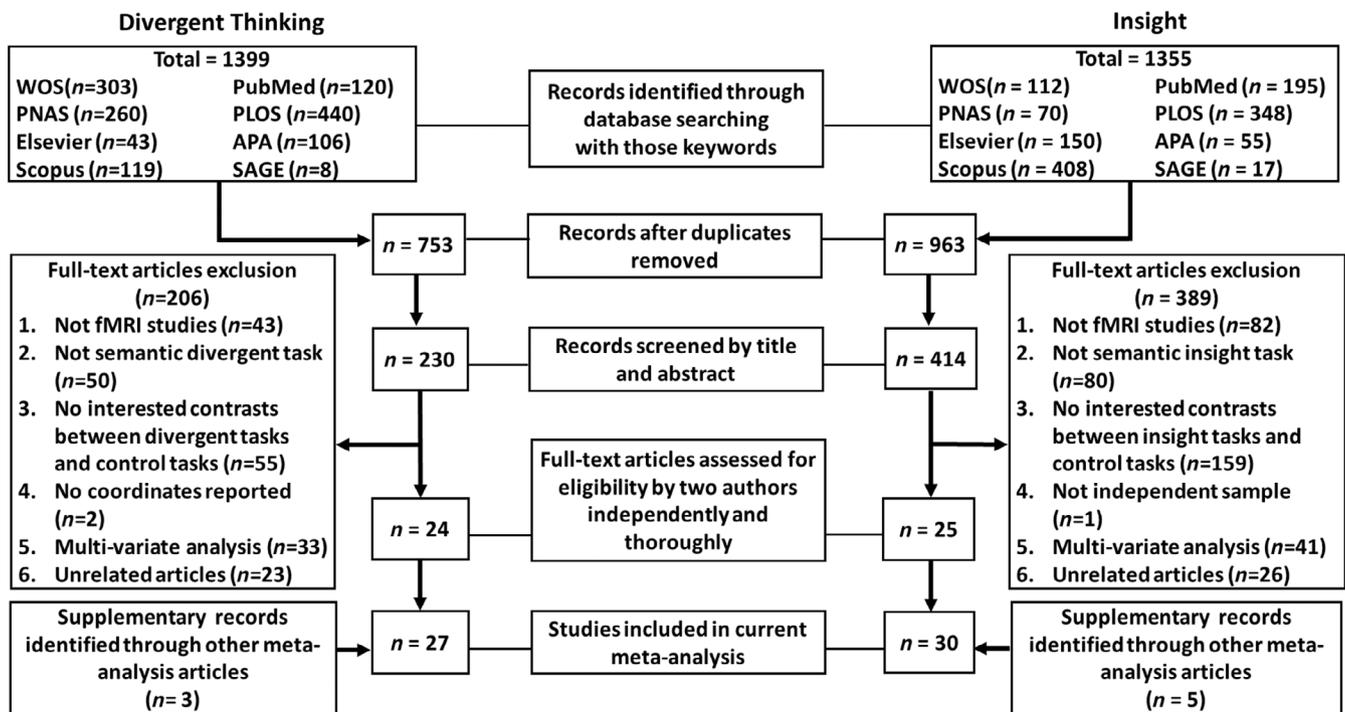
#### 2.1.1 | Search for papers

From 2000 to 2020, relevant literature was reviewed under the guidance of the PRISMA flow diagram (<http://prisma-statement.org/>; Page et al., 2021). This search was carried out using databases such as the Web of Science (WOS), PubMed, PNAS, PLOS, Elsevier, APA, Scopus, and SAGE. Keywords such as “divergent thinking,” “creativity,” “creative thinking,” “semantic processing,” “idea generation,” and “original ideas” were combined with technical terms such as “functional magnetic resonance imaging” and its abbreviation to yield 1399 papers. To discover Insight-papers searching, keywords such as “aha experience,” “insight,” “problem-solving,” “new semantic associates,” “remote associates,” and “heuristic prototype” were combined with the same technical terms mentioned above to yield 1355 articles.

#### 2.1.2 | Inclusion criteria and selection details

To obtain more qualified articles, we screened the reference list of previously published meta-analyses and reviews about the creativity field under the guidance of the PRISMA statement (Figure 1). Articles included in this study met the following criteria: (a) participants were healthy, without taking any drug treatment or any psychotic disorders, (b) coordinates of activation were derived from the whole brain employing Montreal Neurological Institute (MNI) or Talairach space, (c) creative tasks displayed with semantic stimuli, and (d) publications were peer-reviewed.

After removing duplicates and applying the inclusion criteria, 753 DT and 963 insight studies remained. The titles and abstracts were then screened to further ensure their inclusion was appropriate. Following this step, 206 DT studies and 389 insight studies remained. After reading the full text, two trained co-authors implemented a stricter exclusion strategy (Figure 1). During this process, two DT studies were identified as missing coordinates and eliminated, and one insight study was discarded as its sample was not independent. Following these steps, the final ALE analysis included 57 articles. Twenty-seven articles focused on DT and involved a total of 761 participants (female proportion: 45.1%). The remaining 30 articles pertained to studies that assessed insight and contained a total of 571 participants (female proportion: 37.6%; Figure 1 and Table 1).



**FIGURE 1** Flow chart of the screening procedure based on the PRISMA statement for the meta-analysis

## 2.2 | Experiments and contrasts of interest

Within each article, experimental data, which is the coordinates of the experiments, were extracted and reported. “Experiments” referred to contrasts that investigated creativity-related tasks relative to control tasks in DT and insight. Control tasks were defined as uncreative or less creative tasks in DT and noninsight or less insightful tasks in insightful events. We listed all detailed information about the collected contrast in Table S1 and S2, with 36 contrasts from DT and the other 37 contrasts from insight. Noncreative or less creative DT tasks and noninsight or less insightful tasks were accessible in the tables as well.

### 2.2.1 | Contrasts of DT

DT mainly comprises AUT, NMT, VGT, and CSG experiments and their corresponding control tasks. Specifically, in the AUT experiment, participants are required to produce creative uses for conventional everyday objects (e.g., brick, shoes; Abraham et al., 2012; Chrysikou & Thompson-Schill, 2011; Fink et al., 2009). AUTs are usually contrasted with control conditions like the object characteristic task, which asks subjects to generate conventional features of the given daily item (Ivancovsky et al., 2018). In the NMT experiment, subjects must fill in short sentences with figurative metaphors produced themselves (Benedek, Jauk, et al., 2014). In such instances, the experimenter would offer an adjective in parentheses, which is related to the noun's properties, for example, “The lamp is (glaring)” An appropriate answer should creatively convey the meaning of presented adjectives (glaring)

and thus can be used as a replacement it (e.g., “a supernova”). This task's control condition requires that participants produce literally metaphorical expressions without DT. In the VGT experiment, the participants are asked to conceive an unusual verb related to a noun shown on a screen and are encouraged to think creatively. Its control tasks require the participant to produce uncreative verbs or memory recalling (Beaty & Mathias, 2017; Seger et al., 2000). The CSG experiment asks subjects to generate original stories under the given semantic materials, while its matched control tasks generally require subjects to produce ordinary stories or to copy existing narratives (Howard-Jones et al., 2005; Shah et al., 2011).

### 2.2.2 | Contrasts of insight

Well-qualified insight experiments include the CRA, CCD, Chinese logogriphs problem-solving (CLS), and HP problem-solving (Becker et al., 2019b; Lin et al., 2020; Qiu et al., 2010; Shen et al., 2018). During the CRA experiment, three problem words (e.g., pine, crab, and sauce) are allocated at a time. The protocol then demands that participants produce a solution word (e.g., apple), which can be combined with each problem word into a compound word (e.g., pineapple, crab apple, and applesauce). Researchers then contrast successful insight events (find solutions with AHA experience) and unsuccessful ones (find solutions without AHA experience; Jung-Beeman et al., 2004; Mednick, 1962). The CCD experiment comprises two “tight” and “loose” conditions. For example, when participants are involved in Chinese characters decomposition, the tight condition refers to decomposition by removing strokes of the characters, while the loose

**TABLE 1** Details of the selected fMRI studies of ALE meta-analysis

fMRI Studies	Scanner	Sample	Age range (mean)	Foci	Creativity task
<i>Divergent thinking (DT)</i>					
Abraham et al. (2012)	1.5-T MRI	19	19–29 (22.42)	15	AUT
Abraham et al. (2018)	1.5-T MRI	34	22.66 ± 2.88	23	AUT
Beaty and Mathias (2017)	3.0-T MRI	24	18–47 (24.19)	4	VGT
Beaty, Kenett, et al. (2018)	3.0-T MRI	29	18–30 (21.79)	16	AUT
Benedek, Jauk, et al. (2014)	3.0-T MRI	35	18–29 (22.7)	1	AUT
Benedek, Beaty, et al. (2014)	3.0-T MRI	28	19–49 (26.2)	8	NPT
Benedek et al. (2017)	3.0-T MRI	42	24.31 ± 4.3	6	AUT
Benedek et al. (2020)	3.0-T MRI	42	24.34 ± 4.35	10	BAT, OAT
Chrysikou and Thompson-Schill (2011)	3.0-T MRI	24	23.04	3	AUT
Fink et al. (2009)	3.0-T MRI	21	24.29 ± 4.09	1	AUT
Fink et al. (2010)	3.0-T MRI	31	23.19 ± 2.79	7	AUT
Fink et al. (2011)	3.0-T MRI	24	24.9 ± 2.9	4	AUT
Fink et al. (2015)	3.0-T MRI	53	24.04 ± 2.93	4	AUT
Green et al. (2014)	3.0-T MRI	55	22.5 ± 4.78	18	VGT
Heinonen et al. (2016)	3.0-T MRI	16	19–49 (31.3)	3	AUT
Howard-Jones et al. (2005)	1.5-T MRI	8	20.3 ± 1.3	5	CSG
Ivancovsky et al. (2018)	3.0-T MRI	36	Israelis: 26.13 ± 3.23; Koreans: 28.93 ± 7.81	1	AUT
Kleibeuker et al. (2013)	3.0-T MRI	Adolescents: 24; Adults: 19	Adolescents: 16.89 ± 0.63; adults: 26.83 ± 1.37	16	AUT
Kleinmintz et al. (2017)	3.0-T MRI	18	26.06 ± 3.08	4	AUT
Mashal et al. (2007)	1.5-T MRI	15	21–31	23	NMT
Mayseless et al. (2015)	3.0-T MRI	25	25.7 ± 2.3	2	AUT
Seger et al. (2000)	1.5-T MRI	7	31	14	VGT
Shah et al. (2011)	3.0-T MRI	28	24.0 ± 1.9	6	CSG
Sun et al. (2016)	3.0-T MRI	14	19.43 ± 0.85	1	AUT
Sun et al. (2019)	3.0-T MRI	29	19.48 ± 0.74	1	AUT
Vartanian et al. (2013)	3.0-T MRI	17	30.79 ± 7.06	2	AUT
Vartanian et al. (2018)	3.0-T MRI	44	35.47 ± 11.3	14	AUT
<i>Insight</i>					
Anderson et al. (2009)	3.0-T MRI	20	18–32 (23.2)	8	CRA
Aziz-Zadeh et al. (2009)	3.0-T MRI	10	20–40 (26)	8	EAS
Becker et al. (2019b)	3.0-T MRI	27	18–31	3	Modified CRA
Hao et al. (2013)	3.0-T MRI	17	20–25	2	HP
Huang et al. (2015)	3.0-T MRI	15	20–26 (22.36)	13	Chinese CCD
Huang et al. (2018)	3.0-T MRI	20	21–26 (23.75)	5	Chinese RTS
Jung-Beeman et al. (2004)	1.5-T MRI	13	18–29	8	CRA
Kizilirmak et al. (2016)	3.0-T MRI	26	25 ± 3.7	9	German CRA
Kizilirmak et al. (2019)	3.0-T MRI	23	25 ± 2.6	36	German CRA
Kounios et al. (2006)	3.0-T MRI	20	NA	6	CRA
Lin et al. (2020)	3.0-T MRI	32	19–27	7	Chinese CCD
Luo and Niki (2003)	3.0-T MRI	7	20–22	39	Japanese RTS
Luo et al. (2004a)	3.0-T MRI	13	20–43 (26.7)	12	ASC
Luo et al. (2004b)	3.0-T MRI	Total: 21; Condition A: 11; Condition B: 10	21–35	21	Solving cerebral gymnastics puzzles

TABLE 1 (Continued)

Luo et al. (2006)	3.0-T MRI	13	20–27	19	Chinese CCD
Luo et al. (2013)	3.0-T MRI	Exp. 1: 19; Exp.2: 17	Exp. 1: 19–25; Exp. 2: 19–24	3	HP
Pang et al. (2009)	3.0-T MRI	13	20–26	3	Chinese CCD
Qiu et al. (2010)	3.0-T MRI	16	19–25 (22.6)	19	CLS
Sinitsyn et al. (2020)	3.0-T MRI	32	20.5	1	RAS
Subramaniam et al. (2009)	3.0-T MRI	27	NA	7	CRA
Tang et al. (2015)	3.0-T MRI	22	19–26	23	Chinese CCD
Terai et al. (2013)	3.0-T MRI	18	19–36	11	Japanese RAT
Tian et al. (2011)	3.0-T MRI	16	19–25 (22.6)	7	CLS
Tik et al. (2018)	7.0-T MRI	29	27.7 ± 3.7	5	CRA
Tong et al. (2013)	3.0-T MRI	16	20–27 (22.38)	2	HP
Wu et al. (2013)	3.0-T MRI	14	19–25	57	Chinese CCD
Yu et al. (2019)	3.0-T MRI	20	22.95 ± 2.04	39	TMC
Zhang et al. (2014)	3.0-T MRI	18	17–23 (20.3)	2	GIC
Zhao et al. (2014)	3.0-T MRI	17	21–35 (23.6)	26	Chinese “Chengyu” RST
Zhou et al. (2011)	3.0-T MRI	10	19–24 (20.56)	18	TASC

Abbreviations: NA, not available. DT: AUT, Alternative Uses Task, generate multiple uses for conventional everyday objects; BAT, Bi-Association Task, find a concept that is semantically related to both given adjectives originally; CSG, Creative Sentence Generation, produce creative stories using offered semantic materials; NMT, Novel Metaphor Task, decide whether the two words in each pair are metaphorically related; NPT, Novel Production Task, complete the sentence by generating a metaphor response that conveys the meaning of given adjectives; OAT, Original Association Task, find a remotely related concept to a given adjective originally; VGT, Verb Generation Task, generate an unusual verb related to the presented noun. *Insight*: ASC, Ambiguous Sentences Comprehension, comprehend sentences with implicit semantic meanings; CCD, Character Chunk Decomposition, decompose strokes or radicals from existing characters to constitute a new and real character; Chinese “Chengyu” RST, Chinese “Chengyu” Riddle Solving Task, choose one novel and reasonable answer among four presented options; CLS, Chinese Logogriphs Solving, guess the answer of different Chinese logogriphs; CRA, Compound Remote Associates, produce a new word that can form compound real words with each of three presenting hint words; EAS, English Anagrams Solving, figure out correct English words behind the transposed letter orders; GIC, Generation of Inventive Conception, produce a (non) biologically novel concept under the help of presented clues; HP, learn the heuristic prototype then applied them to solve new innovation problems; Japanese RAT, Japanese Remote Associates Task, find the target word to compound with problem words through remote association after semantic chunk decomposition; RAS, Russian Anagrams Solving, figure out correct Russian words behind the transposed letter orders; RTS, Riddle Teaser Solving, guess the answer of different riddle teasers; TASC, Two-part Allegorical Saying (TAS) Comprehension, decide whether the second part of TAS is an existing word; TMC, Therapeutic Metaphor Comprehension, comprehend therapeutic metaphors toward corresponding micro-counseling scenarios.

condition refers to decomposition by removing the radicals of the characters (Huang et al., 2015; Luo et al., 2006; Tang et al., 2015). Therefore, the contrast in insight observed in the CCD experiment is usually defined as “tight chunk > loose chunk” (Pang et al., 2009). In the CLS experiment, subjects are required to resolve a Chinese word riddle. One could attain AHA experience by successfully solving the task (Qiu et al., 2010). For instance, for those who can successfully tackle the riddle, these subjects can understand the superficial and embedded meanings with insightful experience. In contrast, those subjects who fail to tackle the riddle are easily trapped by the superficial meanings. Thus, the contrast in insight in the CLS experiment is defined as “successful > unsuccessful.” In HP problem-solving, subjects often initially study related heuristic cases to identify useful archetype information. Then, the subjects produce new answers by transferring what they have learned into problems to be solved. The control condition requires that experimenters offer unrelated heuristic cases for unsolvable or already solved problems (Luo et al., 2013; Tong et al., 2013).

### 2.3 | Activation likelihood estimation

Standard ALE analysis models use the coordinate of centered activation focus as probability distributions rather than a single point with Gaussian probability density distributions (Wu et al., 2016). The coordinates of centered activation gaussian widths were calculated based on the sample size and inter-subject localization uncertainty. Within each study, specialized software computes the activation probabilities of each voxel. Then, an algorithm will combine these data points and yield an ALE map for the whole brain. After uniting these maps, a voxel-wise statistical ALE map across different studies can be obtained, which allows for the ALE value to be examined (Eickhoff et al., 2009; Turkeltaub et al., 2012). Finally, a permutation test was adopted to generate randomized foci and ALE values, representing the null distribution (i.e., noise). Using these strategies, we could find the real convergence of activation foci, and random clustering can be differentiated (Eickhoff et al., 2012; Turkeltaub et al., 2002).

All confirmed coordinates were analyzed using GingerALE 3.0.2 software (<http://brainmap.org/>). Initially, all coordinates were converted into MNI space using the tal2icbm\_spm transformation (Laird et al., 2010; Lancaster et al., 2007). The current study selected a conservative mask of the MNI152 space. In total, 631 activation foci were analyzed, with the DT and insight dataset comprising 212 foci (10 foci outside the mask); and 419 foci (19 foci outside the mask), respectively. The Mango and the Colin27 template (1 mm × 1 mm × 1 mm; <http://ric.uthscsa.edu/mango>) as well as mricroGL (<https://www.nitrc.org/projects/mricrogl>), were utilized to inspect and display the results.

First, we performed two single meta-analyses on the DT and the insight datasets alone. In each dataset, the qualified contrasts from an independent article were gathered into one group as long as they were derived from the same sample (Müller et al., 2018). Reported foci originating from an identical sample were integrated once only to avoid repeated effects (Eickhoff et al., 2016; Turkeltaub et al., 2012). The initial single meta-analyses contained DT > control and insight > noninsight. Data processing was corrected by multiple comparisons using a Family Wise Error Rate of  $p < .05$  at cluster-level and permuted 3000 times with a cluster forming threshold of  $p < .001$  (Müller et al., 2018). Second, we implemented two contrast analyses and a conjunction analysis to reveal unique and common neural correlations between DT and insight. A pooled dataset was created, whose computing parameters were the same as that in the single meta-analysis, combining foci from the two input datasets of DT and insight. Then, these pooled foci were randomly separated as two simulated datasets. Subtractions were conducted within the simulated datasets and input datasets, respectively. The subtraction results of the simulated datasets were compared with the input datasets using the  $p$ -value. Specific contrast analyses included DT > insight and insight > DT; conjunction analysis was DT  $\cap$  insight. Parameterized details were as follows:  $p$ -value was calculated, and  $p < .01$ . The minimum volume of a cluster is 100 mm<sup>3</sup> with a 3000 times permutation.

## 3 | RESULTS

### 3.1 | Single dataset analysis

#### 3.1.1 | DT > control

From the initial single dataset analyses, three clusters were observed to be activated in DT (Table 2 and Figure 2). The first cluster was located in the left parietal lobe and consisted of the following specific elements: 73.3% of the IPL, 23.3% of the postcentral gyrus (PoCG), and 3.4%SMG [its coordinates ranged from (−64, −36, 30) to (−50, −20, 46) centered at (−57.5, −29.1, 38.8) with a peak ALE value of 0.034, BA 40, 2, 1]. The second cluster was positioned in the right occipital lobe and consisted of 85.4% of the CUN and 14.6% of the LG [its coordinates ranged from (8, −92, 6) to (18, −80, 18) centered at (12.8, −87.1, 12.9) with a peak ALE value of 0.025, BA 17, 18]. The third cluster was located in the left frontal lobe and was comprised 77.4% of the MFG, 22.6% of the IFG [its coordinates ranged from

(−54, 28, 8) to (−44, 40, 18) centered at (−49, 35.1, 13.8) with a peak ALE value of 0.022, BA 46].

#### 3.1.2 | Insight > noninsight

Four clusters displayed elevated activation in the insight condition relative to those in the noninsight (Figure 2 and Table 2). The most exact and largest cluster location was observed in the left frontal lobe and was comprised of 37.1% of the PreCG, 31.8% of the IFG, 31.1% of the MFG [its coordinates ranged from (−54, 2, 20) to (−36, 22, 52) centered at (−47.1, 10, 34.3) with three peaks, a max ALE value of 0.028 and BA 6,9,8]. The second cluster was identified across the left sub-lobar and limbic lobe and was comprised of 47.2% of the PG and 43.8% of the lentiform nucleus (mostly Amygdala) [its coordinates ranged from (−30, −12, −20) to (−16, 0, −8) centered at (−22.4, −6.3, −13.4) with one peak ALE value of 0.026]. The third cluster was found in the left parietal lobe and encompassed 54.5% of the PCUN, 34.1% of the SPL, 11.4% of the IPL [its coordinates ranged from (−34, −74, 38) to (−20, −54, 54) centered at (−27.1, −65, 45.5) with two peaks, a max ALE value of 0.023, BA involved 7, 19, 39]. The fourth cluster was mainly identified in the right frontal lobe (92.4%). It was made up of 53.2% of the SFG, 36.7% of the medial frontal gyrus, and 10.1% of the CG [its coordinates ranged from (−2, 10, 44) to (12, 20, 54) centered at (6.7, 14.8, 49.2) with a peak ALE value of 0.0275, BA 6, 32, 24].

## 3.2 | Contrast analyses and conjunction analyses

### 3.2.1 | DT > insight

Our contrast and conjunction analyses highlighted two clusters that displayed stronger activation in the DT condition relative to those observed in insight (Figure 3 and Table 3). The first cluster was identified in the left IPL (73.9%) as well as 22.6% of the PreCG and 3.5% of the SMG [its coordinates ranged from (−64, −36, 30) to (−50, −22, 46) centered at (−57.6, −29.4, 38.6) with two peaks, a max ALE  $z$ -value of 2.935, BA 40, 2]. The second cluster was located in the right occipital lobe and was comprised of 76.9% of the CUN and 23.1% of the LG [its coordinates ranged from (10, −92, 8) to (16, −86, 16) centered at (13.9, −89.7, 12.7) with two peaks, a max ALE  $z$ -value of 2.576, BA 17].

### 3.2.2 | Insight > DT

Four clusters were detected in insight compared to DT (Figure 4 and Table 3). The location of the first and largest cluster was in the left frontal lobe and was comprised of 38.8% of the PreCG, 34.1% of the MFG, and 27.1% of the IFG [its coordinates ranged from (−54, 4, 26) to (−40, 22, 52) centered at (−46.7, 10.9, 36.9) with three peaks, a max ALE  $z$ -value of 3.090, BA 9,6,8]. The next cluster was mainly

**TABLE 2** Brain activations of single dataset analysis in divergent thinking (DT) and insight

Cluster	Volume	Peaks	L/R	Brain regions	BA	x	y	z	ALE value	Contributors to cluster
<i>DT &gt; Control</i>										
1	1928	1	L	Inferior parietal lobe (extending to postcentral gyrus and supramarginal gyrus)	40	-58	-30	40	0.034	Abraham et al. (2012) Abraham et al. (2018) Beaty, Thakral, et al. (2018) Benedek, Beaty, et al. (2014) Benedek and Jauk (2018) Fink et al. (2010) Fink et al. (2015) Kleibecker et al. (2013) O. Vartanian et al. (2018)
2	936	1	R	Cuneus (extending to lingual gyrus)	17	12	-88	12	0.025	Abraham et al. (2018) Fink et al. (2010) Green et al. (2014) Sun et al. (2016 Exp. 1) Sun et al. (2019)
3	808	1	L	Middle frontal gyrus (extending to inferior frontal gyrus)	46	-48	36	14	0.022	Mashal et al. (2007) Beaty and Mathias (2017) O. Vartanian et al. (2013)
<i>Insight &gt; noninsight</i>										
1	3064	1	L	Precentral gyrus (extending to inferior frontal gyrus and middle frontal gyrus)	6	-50	6	28	0.028	Huang et al. (2015) Kizilirmak et al. (2016) Kizilirmak et al. (2019)
		2	L	Middle frontal gyrus	6	-46	10	40	0.022	Luo et al. (2006) Wu et al. (2013)
		3	L	Middle frontal gyrus	6	-42	18	48	0.018	Zhao et al. (2013) Luo et al. (2004a) Qiu et al. (2010) Tang et al. (2015) Tong et al. (2013)
2	1376	1	L	Lentiform nucleus (extending to parahippocampal gyrus-amygdala)	\	-22	-4	-12	0.026	Huang et al., 2015 Kounios et al., 2006, Exp. 2 Yu et al. (2019) Zhao et al. (2013) Zhou et al. (2011, Exp. 3) Jung-Beeman et al. (2004, Exp. 1)
3	1376	1	L	Precuneus (extending to superior parietal lobule and inferior parietal lobule)	19	-26	-70	42	0.023	Kizilirmak et al. (2019) Wu et al. (2013) Luo et al. (2004a) Luo et al. (2004b) Qiu et al. (2010) Tang et al. (2015)
		2	L	Superior parietal lobule	7	-30	-58	48	0.021	
4	936	1	R	Superior frontal gyrus (extending to medial frontal gyrus and cingulate gyrus)	6	8	14	50	0.027	Kizilirmak et al. (2019) Wu et al. (2013) Luo et al. (2004a)

Note: These two single data analyses were corrected by family-wise error at the cluster level, respectively, whose threshold was  $p < .05$  with 3000 times permutation and cluster forming threshold was  $p < .001$ . Volume refers to the size of the cluster ( $\text{mm}^3$ ). Montreal Neurological Institute coordinates were used. Abbreviations: BA, Brodmann area; Exp, experiment; L/R, left hemisphere or right hemisphere.

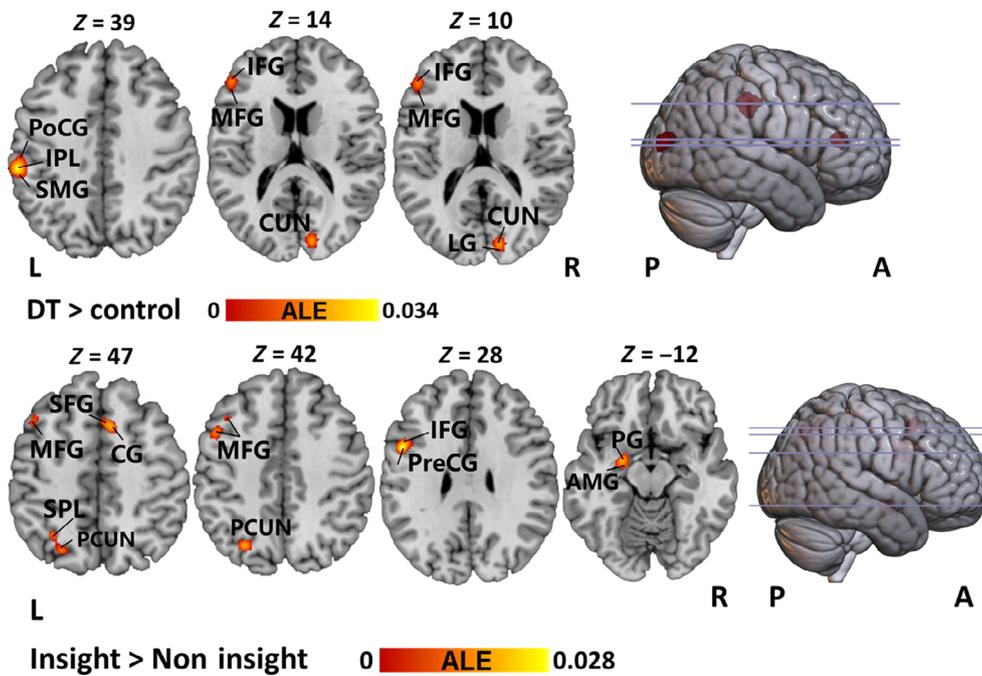
identified in the right frontal lobe; however, it extended to the medial frontal gyrus (MedFG; 72.7%), CG (24.2%) and SFG (3%) [its coordinates ranged from (4, 10, 44) to (12, 18, 52) centered at (9.4, 12.5, 48.1) with a peak ALE z-value of 3.090, BA 32, 6, 24]. The third cluster was localized in the left parietal lobe and encompassed 85.7% of the SPL, 7.1% of the PCUN, 7.1% of the IPL [its coordinates ranged from (-34, -62, 44) to (-26, -56, 54) centered at (-29.6, -58.7, 49.6) with two peaks, a max ALE value of 3.588, BA 7, 19]. The last cluster was found on the left side, across the limbic lobe (60%) and sub-lobar (40%), where the PG and AMG accounted for 60% of the cluster while the remaining 40% was comprised the lentiform nucleus.

### 3.2.3 | DT ∩ insight

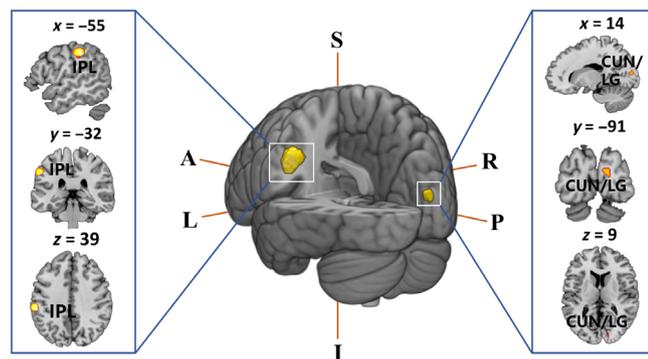
No overlapping clusters were found under the current ( $p < .01$ ) or less strict threshold parameters ( $p < .05$ ).

## 4 | DISCUSSION

The present study aimed to unravel distinctive and common neural mechanisms between two different creativity thinking subsets (DT and insight) based on dual-process theory. Toward this end, we have conducted two single analyses, two contrast analyses, and a



**FIGURE 2** Clusters activated significantly (FWE-corrected  $p < .05$  with 3000 permutations, cluster forming threshold  $p < .001$ ) in a single dataset analysis (DT > control, insight > noninsight). A, anterior; AMG, amygdala; CG, cingulate gyrus; CUN, cuneus; IFG, inferior frontal gyrus; IFG, inferior frontal gyrus; IPL, inferior parietal lobe; L, left; LG, lingual gyrus; MFG, middle frontal gyrus; P, posterior; PCUN, precuneus; PG, parahippocampal gyrus; PoCG, postcentral gyrus; PreCG, precentral gyrus; R, right; SFG, superior frontal gyrus; SMG, supramarginal gyrus; SPL, superior parietal lobe



**FIGURE 3** Clusters activated significantly ( $p < .01$  with 3000 permutations, minimized volume of cluster forming threshold was  $100 \text{ mm}^3$ ) in a contrast dataset analysis (DT > insight). A, anterior; I, inferior; IPL, inferior parietal lobe; L, left; LG, lingual gyrus; P, posterior; R, right; S, superior

conjunction analysis using the ALE method. Twenty-seven DT studies and 30 insight studies were selected for these analyses. The single dataset analyses indicated that the left IPL, right CUN, and left MFG were coherently involved in DT, while insight mainly recruited clusters in the left PreCG/IFG, left PG, left AMG, left PCUN, and right SFG. In contrast analyses, robust activation was significantly detected in the left IPL (key node of the DMN) and right LG in DT instead of insight activity. Conversely, areas like the left PreCG/IFG, right CG/MedFG, left SPL, and left PG/AMG were significantly activated during insight than DT. However, no overlapping clusters were observed in the conjunction analysis of these two creative events. These results could probably reflect that DT mainly demanded the DMN while insight might ask for the participation of the Executive Control Network (ECN) and the hippo-amygdala network for emotional responses.

Compared to the previous meta-analyses in DT or insight (i.e., Boccia et al., 2015; Cogdell-Brooke et al., 2020; Shen et al., 2018; Shen, Yuan, Liu, Zhang, et al., 2016; Wu et al., 2016), which is prone to focus on only one type of creative subset alone and cannot provide the common and specific neural evidence underlying DT and insight. Our current research steps forward to perform contrast and conjunction analyses between DT and insight. Single analyses from preceding studies had little access to cross-sectional comparison, and thus they failed to portray neural differences between DT and insight. However, from the contrast and conjunction analysis, we could resolve the unanswered details, including not only the coherent brain activation but also the dominant contribution of different brain networks in DT and insight. Moreover, our findings may deliver vigorous neural evidence for theoretical dual-process systems in creative thinking. To be more specific, we speculated that DT activities largely count on the DMN to support System 1's operation to complete information retrieval and extraction multidimensionally and massively. On the other hand, insightful events typically activate the ECN underlying System 2, paving the way to successful but slow completeness requiring great mental endeavor.

## 4.1 | Clusters activated in single dataset analysis

### 4.1.1 | DT > control

DT requires the involvement of crucial abilities to be involved in creative idea generation, such as flexibly retrieving long-term memory (Silvia et al., 2013), constructing novel associations between remote concepts (Benedek, Könen, et al., 2012), redirecting attention resources (Dietrich & Kanso, 2010), and conducting imaginative simulation (Lebouillier & Marks, 2003; Zhang et al., 2019). Our results

**TABLE 3** Brain activations of contrast and conjunction dataset analysis between divergent thinking (DT) and insight

Cluster	Volume	Peaks	L/R	Brain regions	BA	x	y	z	ALE z-value	Contributors to cluster
<i>DT &gt; Insight</i>										
1	1824	1	L	Inferior parietal lobule (extending to postcentral gyrus and supramarginal gyrus)	40	-55.4	-32.2	39.3	2.935	Abraham et al. (2012) Abraham et al. (2018) Beaty, Kenett, et al. (2018) Benedek, Beaty, et al. (2014) Benedek and Jauk (2018) Fink et al. (2010) Fink et al. (2015) Kleibeuker et al. (2013)
		2	L	Inferior parietal lobule	40	-59.3	-28	35.8	2.878	
2	296	1	R	Lingual gyrus	17	14	-92	10	2.576	Abraham et al. (2018)
		2	R	Cuneus	17	11.6	-90.4	13.2	2.424	
<i>Insight &gt; DT</i>										
1	1504	1	L	Precentral gyrus	6	-47.5	8	34.5	3.090	Huang et al. (2015)
		2		Inferior frontal gyrus	9	-44	10	31	3.209	Kizilirmak et al. (2019) Zhao et al. (2013)
		3		Middle frontal gyrus	6	-45.3	17.7	46.7	0	Qiu et al. (2010) Tong et al. (2013)
2	368	1	R	Cingulate gyrus (extending to medial frontal gyrus and superior frontal gyrus)	24	12	10	46	3.090	Wu et al. (2013) Luo et al. (2004a)
3	328	1	L	Superior parietal lobule (extending to precuneus and inferior parietal lobule)	7	-30	-58	54	3.588	Kizilirmak et al. (2019) Luo et al. (2004b) Qiu et al. (2010)
		2		Angular gyrus	39	-30	-60	44	2.935	
4	296	1	L	Parahippocampal gyrus (extending to amygdala)	34	-18	0	-14	2.681	Huang et al. (2015) Yu et al. (2019)
		2		Lentiform nucleus (extending to lateral globus pallidus)	\	-21	0	-10	2.652	

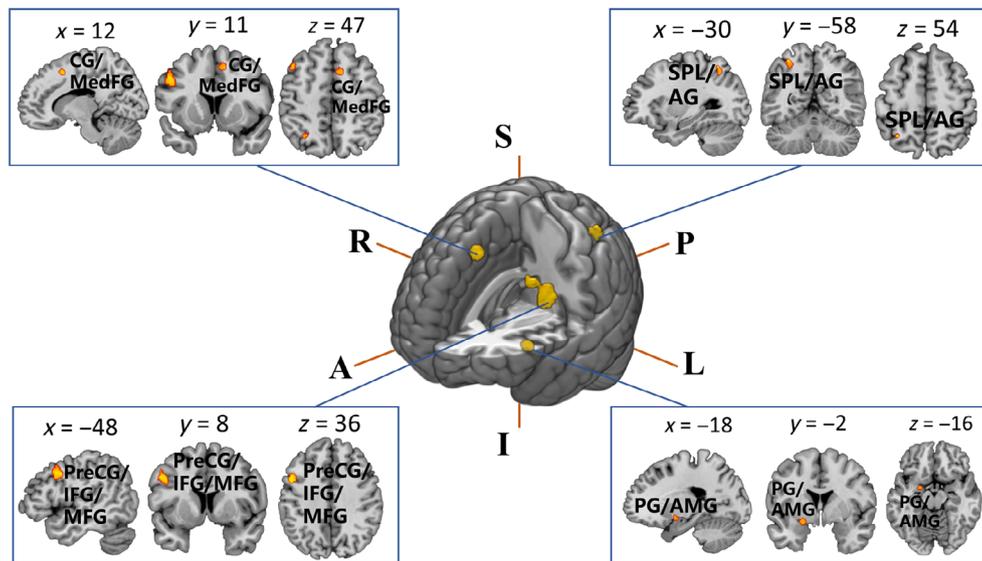
Note:  $DT \cap Insight$ : No clusters were found. These two contrast data analyses were analyzed with a threshold at  $p < .01$  with 3000 times permutation, and the minimized volume of cluster forming threshold was  $100 \text{ mm}^3$ . Volume refers to the size of the cluster ( $\text{mm}^3$ ). Montreal Neurological Institute coordinates were used.

Abbreviations: BA, Brodmann area; Exp, experiment; L/R, left hemisphere or right hemisphere.

showed that the left IPL was active in DT. This observation is likely correlated with its roles in supporting autobiographical memory retrieval and semantic association combination under DT. Indeed, previous studies have provided evidence to support IPL's contribution toward episodic memory and semantic demands (Benedek et al., 2018; Igelström & Graziano, 2017; Wu et al., 2015), with the SMG potentially undertaking an essential role in allocating attentional resources toward useful memory (Cabeza et al., 2008). Previous studies have shown that the IPL was always activated across AUTs during a conceptual expansion (Benedek, Jauk, et al., 2014; Vartanian et al., 2018). Some researchers speculate that the left IPL might interact with abstract tool manipulation in this task (Cogdell-Brooke et al., 2020; Matheson & Kenett, 2020). Notably, the SMG assisted in constructing new representations by integrating memory with innovative strategies that facilitate the imaginative

simulation underlying the generation of new ideas (Benedek et al., 2017). Together, the IPL and SMG can be assumed to promote idea generation in DT.

Additionally, the activation of the CUN/LG was observed during DT. In agreement with previous findings, the CUN/LG was engaged in vivid mental imagery (Andreasen & Ramchandran, 2012; Jauk et al., 2015), which is an important DT processing strategy. Furthermore, Zhang et al. (2016) reported that when assessing the mediation role of bilateral LG's grey matter volume (GMV) between cognitive inhibition and DT performance, the GMV of the right CUN was positively tied to the index of originality, idea fluency, and the verbal creativity (Erhard et al., 2014; Fink et al., 2013). As the CUN/LG cluster was significantly active in the current analysis, our results support the hypothesis that this cluster may have a crucial role in dealing with the novelty and creativeness of DT processes.



**FIGURE 4** Clusters activated significantly ( $p < .01$  with 3000 permutations, minimized volume of cluster forming threshold was  $100 \text{ mm}^3$ ) in a contrast dataset analysis (insight > DT). A, anterior; AG, angular gyrus; AMG, amygdala; CG, cingulate gyrus; I, inferior; IFG, inferior frontal gyrus; L, left; MedFG, medial frontal gyrus; MFG, middle frontal gyrus; P, posterior; PG, parahippocampal gyrus; PreCG, precentral gyrus; R, right; S, superior; SPL, superior parietal lobe

Our data indicated that the activity of the MFG (extending to the IFG) cluster was correlated to DT. The left MFG/IFG appeared to be a task-switcher in supporting DT. Previous studies have suggested that these brain regions are specialized in cognitive flexibility (Kleibecker et al., 2013) and assist with semantic processing (Binder et al., 2009; Noonan et al., 2010), working memory retrieval and selection (Liakakis et al., 2011). More importantly, the left MFG/IFG has contributed to cognitive control (Mayseless et al., 2015). Interestingly, patients with IFG injuries scored higher on originality than those with localized lesions in the Torrance Test of Creative Thinking (Shamay-Tsoory et al., 2011). Besides, Kleinmintz et al. (2017) also postulated that inhibiting IFG's activity might enhance the novel ideas' release more freely. Therefore, the activity of this cluster may explain the tendency to produce massively diverse but appropriate DT answers.

#### 4.1.2 | Insight > noninsight

Insight is interpreted as a dynamic cognitive process characterized by the unexpected comprehension of mental impasses (Jung-Beeman et al., 2004). Those who can solve tricky problems may sequentially break mental fixedness, reconstruct representations, inhibit prepotent responses, rebuild novel associations and finally figure out the correct answer creatively, a process that, if successful, is accompanied by positive emotional feelings (Shen et al., 2018). In the current study, we provided evidence that the frontal areas (i.e., IFG, MFG, and SFG) contribute significantly to the insightful experience. Functionally, the IFG and MFG have been highlighted as being key in forming new associations and breaking rigid mental mindsets (Qiu et al., 2010; Shen et al., 2018). Structurally, the white matter density of left IFG was negatively correlated to the Remote Associates Task's score (Li et al., 2019). It is hypothesized that the increased cognitive efficiency observed in superior perception events requires a decreased cortical thickness of the frontal lobe, a physiological phenomenon that might accelerate

filtering, selecting, and integrating semantic information (Ernst & Korelitz, 2009; Shaw et al., 2006). Additionally, previous studies have provided evidence to show that the activation of SFG (extending to CG) is associated with executive control (i.e., error detection, conflict monitoring, and attention control) needed by insight (Li et al., 2013).

Remarkably, the PG and AMG activity was detected in the insightful condition. Insight depends on relative information retrieval of the working memory, which is largely correlated with PG activity (Wang et al., 2009). Additionally, the AMG is known to be sensitive to emotional reactions if the insight was effectively induced (Girardeau et al., 2017; Tik et al., 2018). Thus, the activated status in this area is not surprising. The AMG is the core of the affective network and is sensitive to emotive experience (Pessoa & Adolphs, 2010; Shen et al., 2018). The affective role of AMG is accepted in insight, and its activity also corresponds to novelty detection (Blackford et al., 2009; Schwartz et al., 2003) and usually collaborates with the hippocampus (Rutishauser et al., 2006; Yang & Wang, 2017). It is understood that the PG activity peaks when participants identify old configurations during associative recognition (Düzel et al., 2003). Furthermore, we suppose that the PG likely contributes to establishing and integrating distant, weak, and existing associations to support insight. Hence, it is reasonable that the AMG explains the AHA experience as well as the creative solutions presented in insight.

Our results highlighted increased activity from the SPL (i.e., PCUN). Several studies have shown that the PCUN, whose activation spread across different insight tasks, might be indispensable in attention and representation perception when dealing with problematic dilemmas (Kizilirmak et al., 2019; Luo et al., 2004a, 2004b; Tang et al., 2015). However, the PCUN is interrelated to successful episodic memory retrieval (Dobbins et al., 2003; Ludmer et al., 2011) and conscious information processing (Kjaer et al., 2001; Vogt & Laureys, 2005). Together, these findings suggest that the PCUN/SPL could bridge the gap between external knowledge and self-awareness in insight.

## 4.2 | Clusters activated in contrast analysis

### 4.2.1 | DT > insight

DT is characterized by a massive and parallel creative flow of ideas whose originality comes quickly, intuitively, and associatively (Doyle, 2017). Unlike insight, DT allows for defocused attention, and it is hypothesized that a rich production of creative thought is derived from an effortless and automatic thinking mode with less cognitive control. The collection of useful long-term knowledge from daily life can be extracted easily and is described as experiential. Such intricate processing patterns in DT may require unique neural pathways. According to our results, two clusters displayed significantly enhanced activation in DT compared to insight. One was located in the left IPL, and the other was in the right CUN/LG.

The IPL generally relays memory retrieval, where associations between empirical experience and novelty are stored. In the current study, IPL activity significantly emerged in single and contrasted analyses and appeared to be specific for DT events. The IPL is one of the crucial nodes in the DMN (Buckner et al., 2008). The DMN is associated with creativity through the accumulation of evidence. In support of these ideas, several connectivity-based neuroimaging studies have confirmed the IPL's contribution to boosting creative task performance, especially in DT (Beaty et al., 2014; Beaty, Thakral, et al., 2018). The automatic associative thinking mode in DT has been attributed to the DMN with chain-free association tasks (e.g., AUT, VGT; Badre & Wagner, 2007; Marron et al., 2018). These tasks require subjects to produce quality novel ideas from different concepts without strict standards and are referred to as being free characterized (e.g., produce a verb from your first mind related to the presented noun). The DMN is also responsible for self-monitoring, internal attention, autobiographical memory retrieval, and mind wandering (Andrews-Hanna, 2012; Bressler & Menon, 2010; Madore et al., 2017; Zabelina & Andrews-Hanna, 2016). However, its role in automatic behavior should be highlighted. Recently, Vatanserver et al. (2017) provided evidence that the DMN assisted in automated information processing (e.g., rapid selection of appropriate responses under a specific and predictable context). They reported increased DMN connectivity when applying learned rules under the cognitive flexibility task. This finding suggested that the DMN may contribute to the integration of memory-stored information. Additionally, those authors reported that the DMN cooperated with the primary visual cortex when responding to correct answers, whose connectivity data correlated to faster reaction time. Therefore, it is hypothesized that the DMN may be the neural basis of autopilot and fast thinking modes embedded in the human brain (Gronchi & Giovannelli, 2018; Raichle, 2015). Together, these data probably offer hints for the existence of System 1 when individuals undertake highly creative events. Therefore, our results indicate that DT mainly processes with an associative, autonomous, and fast thinking pattern (System 1).

### 4.2.2 | Insight > DT

Insight is a high-level cognitive activity characterized by reflective progression steps such as breaking unwanted fixations, reorganizing

representations, and forming novel associations (Becker et al., 2020; Luo & Niki, 2003). The problematic cases that induce insight tend to instruct subjects to concentrate on the current settings and exploit contextual rules. Unlike DT, successful insight is usually associated with self-generated emotional experience (i.e., AHA response). These variations might propose its exclusive role in processing modes. Our data indicated that activation spread from the frontal to the parietal area. Most of these regions were located in the ECN, an area recognized to be important in rule-based creative problem-solving (Beaty et al., 2016). The ECN, with great emphasis on PFC's contribution, extensively contributes to the following cognitive processes: selective attention, information manipulation, response inhibition, and task-oriented representation (Bunge & Souz, 2009; Seeley et al., 2007). Additionally, the PFC assists in sorting out useful thoughts and actions concerning internal goals (Koechlin & Summerfield, 2007). It is also understood that the key nodes of the PFC (i.e., IFG, MFG) are associated with cognitive control and form the neural basis of set-shifting (Aron et al., 2003; Brass et al., 2005; Lin et al., 2020). Controversially, Ogawa et al. (2018) suggested that creative insight could be affected by other large-scale networks aside from the ECN since successful insight relies on multiple effortful procedures. Our results showed the activation was scattered to the MedFG as well. Schuck et al. (2015) suggested that the MedFG might encode irrelevant clues for the current task but is necessary to prepare for alternative strategies later. Furthermore, this cerebral area is inferred to be alternatively involved in enhancing persistent motivation for problem-solving (Shen et al., 2018). Given that the insight process usually occurs after encountering continuous thinking impasses, we speculate that the changes in MedFG activity correlate to changes observed when breaking the impasse in insight. Negative feedback drives subjects to prolong time expenditure, exert stronger internal monitoring during attempts, and facilitate mental simulation to achieve problem-solving objectives.

In our contrast analysis, significant right CG activation was noted. The CG belongs to the salience network (SN) and encompasses the ACC (Jung, 2013). The SN is associated with goal-directed behaviors and is understood to coordinate and allocate brain resources for numerous external stimuli in a mutual competing relationship (Uddin, 2017). The ACC, in particular, responds to conflict detection and monitoring, which has been confirmed in numerous fMRI studies. For instance, Anderson et al. (2009) concluded that the ACC facilitates setting subgoals. Those beneficial subgoals can help out in solving the problem step by step. MacDonald et al. (2000) have found that high conflict (e.g., larger reaction time interference effect) was associated with more ACC activity in the Stroop task. The ACC can monitor and react to situations where appropriate responses are difficult due to competition failure with other activities and then allocate extra attention with self-attentional control (Luks et al., 2002). Therefore, the ACC is inferred to represent and maintain the flow of contextual information necessary for mental processing when unrelated noises are predominant. Based on these data, the ACC may display enhanced sensitivity to prevent irrelevant but prepotent ideas and reconstruct novel ideas related to the AHA experience (Lin et al., 2018).

The left SPL's constant activation was evident in the current analysis. SPL activation has been highlighted as an integral part of the orientation of external sensory stimuli in the dorsal attention network (DAN; Petersen & Posner, 2012). This function helps insight perception because top-down progression and regulation require reorienting attention in a goal-directed manner (Hopfinger et al., 2000). To be more specific, researchers discovered that the SPL facilitates sudden comprehension in the CRA (Kizilirmak et al., 2019) and the manipulation of tight/loose pieces in the CCD (Tang et al., 2015). When solving abstract reasoning tests, bilateral SPL activation has been characterized as a key parameter of the logic-based analytic system (System 2), with impaired task performance destructed by transcranial magnetic stimulation in these areas (Tsuji et al., 2011). Together, these lines of evidence suggest that the SPL has a specialized relationship with working memory and promotes executive processes essential for deductive reasoning.

Importantly, the PG/AMG was specifically activated in aha-related events during insight relative to DT. The cognitive roles of this cluster have been discussed in insight and are thought to be essential in the explicit retrieval of memories (Kim, 2015; Yang et al., 2008), the establishment of novel associations (Aminoff et al., 2013), and rewarding nature after working through difficulty (Amir et al., 2015). Intensive thinking is often observed in insight, asking for devoted input of cognitive resources. Thus, positive emotional responses (i.e., happiness, ease, and relief) are more commonly seen if subjects have achieved the goal, a situation in which AMG always responds. Our data indicate that the left PreCG/IFG, right CG/MedFG, left SPL, and left PG/AMG all elicit stronger activation in insight when compared with DT. This outcome implies that insightful events need an effortful processing circuit with conscious control, analytical rules, and a relatively slow pace.

### 4.3 | Conjunction analysis

The conjunction analyses showed no overlapping clusters between DT and insight at the test threshold ( $p < .01$ ). This result led us to reflect on whether the strict threshold might hinder the potential subtle commonalities from being reported. Then, we exploited a relative lenient threshold ( $p < .05$ ), but the result was still the same as before. In retrospect to the two single analyses, similar activation (i.e., IFG, MFG, and IPL) were reported. We believe these two creativities may have some subtle commonalities, but the existing statistical technique is beyond sensitive to reflect such microscopic essence. In contrast to the commonalities, the distinctions were more sizeable, which suggests they are possibly prepared with dissimilar dominant systems. This finding seems to align with our hypothesis that DT and insight were equipped with distinct neural frameworks based on the dual-process theory. Specifically, DT mainly reflected the key features of fast thinking, which relies on the associative process (System 1) to some extent (Lin et al., 2011; Lin & Lien, 2013). This association is attached to the prior experience accumulated over time with existing defocused attentional systems (Smith & DeCoster, 2000; Zabelina &

Ganis, 2018). Distributing one-piece attention resources into smaller ones could promote intensive mental activities, thus allowing for more effective and substantial production of ideas as more information could be noticed and absorbed. This cognitive progression was characterized by autonomous and low cognitive load processes that exemplify DT (Evans, 2003, 2008, 2011; Gilhooly et al., 2007). However, insight, mainly typified as slow thinking, is an unexpected comprehension of concrete problem circumstances and is interpreted as a deliberate and logical process (Lin et al., 2011; Lin & Lien, 2013). This perceptive event requires conscious control and effortful maneuver (System 2; Allen & Thomas, 2011). The exertion of considerable awareness and serial analytical attempts showcase the high cognitive load of generating insight as well as highlighting its high risk of failure. Constant negative feedback can easily get subjects stuck on stiff impasses. On this basis, the underlying cognitive system must recode and reconstruct representations, taking advantage of rules newly acquired from the problem situation (Smith & DeCoster, 2000). The window of attention or focus is relatively narrow, distractions are inhibited, and subjects can grasp direct clues of the current problematic space (Wiley & Jarosz, 2012). MacGregor et al. (2001) have proposed a progress-monitoring prototype to better understand insight problem-solving. A criterion is primarily set for satisfactory progress when tackling a problematic case. However, if the criterion is violated unexpectedly, an impulse will be boosted to seek alternative operators; therefore, it can make sure mental endeavor is back on the right track to solve the problem. All in all, the two different cognitive processes might account for no overlapped clusters between DT and insight in our present study.

As creative cognition is so multifaceted, it is too decisive to claim that insight or DT is supported one-sidedly by System 1 (fast thinking) or System 2 (slow thinking; Benedek & Jauk, 2018; Sowden et al., 2015). According to previous studies, DT needs executive functions like cognitive inhibition to promote idea generation, which is key in overcoming irrelevant responses to the first salient thought (Benedek, Franz, et al., 2012; Radel et al., 2014; Seger et al., 2000). The DMN and the ECN's coupling somewhat support idea generation in DT (Beaty et al., 2015, 2016; Beaty & Silvia, 2012). Similarly, based on structural connectivity evidence, Ogawa et al. (2018) stated that creative insight required the DMN's contribution. And our result also revealed that part of DMN was activated (i.e., the MedFG) in insight. If the DMN's memory-based associative processing fails to approach unpredictable and novel stimuli, external attention, and processing of perceptual information, facilitated by the DAN, will be in demand (Vatansever et al., 2017). Thus, the two cognitive systems may coexist; however, the leading participative role is environmentally task-dependent. Mounting evidence shows that the controlled and effortful processes gradually dominate reasoning in finishing insightful tasks and that the autonomous and associated process probably plays a critical role in DT (Barr et al., 2014; Gronchi & Giovannelli, 2018; Lin et al., 2011; Lin & Lien, 2013). Our single and conjunction analysis results are in agreement with previously published work. For instance, the largest activated cluster in the single analysis of DT was in the IPL; the activation spread to the MFG/IFG implies that DT probably

involves some features of slow thinking (System 2). A similar phenomenon was found in insight problem solving, partially linked to fast thinking (System 1). Additionally, we found no shared activated areas in the conjunction analysis between DT and insight, hinting that the two thinking modes depend on different processes. Therefore, our findings provide neural evidence for the dual-process system hypothesis in creative thinking.

#### 4.4 | Limitations and future directions

This study has several limitations. First, the coordinate-based ALE technique uses activated coordinates and sample size across all the experiments included in our analyses. These collected data are tested for spatial convergence under a specific null space while the specific difference information is lost. Thus, as the effect size is inaccessible, a significant result can only be interpreted as the difference in convergence in contrast to the strength or decrease/increase of the observation (Müller et al., 2018). Second, to maintain the consistency of the null space to be tested, ROI-based research was not considered. This approach limited external validation and may have induced some bias in our findings (Müller et al., 2018). Third, subjects finished experimental tasks with diverse response requirements (e.g., oral response, physical response, or without overt response). This inconsistency may cause a confusing interpretation of the activation results. As the method of answering was not controlled, these tests possibly measured verbal and motor functions rather than pure creative thinking. Thus, it would be incorrect to say with certainty that the activated brain regions observed directly result from insight and DT. Fourth, the heterogeneity of the statistical-processing method (e.g., parameter analysis) and apparatus device (e.g., 1.5-T MR, 3.0-T MR, and even 7.0-T MR) had a wide disparity. Thresholds for determining cluster size and the significance test employed varied largely. These differences may have biased our findings and affected the quality of our consciousness. Finally, the dual-process theory could only partially account for the psychological thinking patterns described in this study. The creative process is achieved through many integrated complex cognitive abilities. Further research should carefully substantiate its applicability in creativity mechanisms with neuroscientific evidence. Although our present meta-analysis is built upon richer data than previous ones, there is still plenty of room for future neurobiological imaging to answer key gaps in the knowledge regarding the multifaceted nature of creativity. Future work could further define figural and arithmetic creativity (e.g., the matching problem) and their co-assisted networks. The current study just aims to reveal the common and distinctive localized consistent activation between DT and insight, so it misses out on valuable functional connectivity data. With functional connectivity analysis becoming more common, there is an increased opportunity to conduct meta-analysis connectivity modeling (MACA) research (Lancaster et al., 2005; Langner et al., 2014; Langner et al., 2021; Robinson et al., 2010). This method could take advantage of dynamic brain patterns to further unlock sealed functional relations in DT and insight. Moreover, some researchers have raised that task

time could potentially affect creative performance (Paek et al., 2021; Wieth and Zacks, 2011). It would be interesting to explore the corresponding neural mechanisms between DT and insight in the future.

## 5 | CONCLUSION

This meta-analysis explored common and specific neural pathways involved in open-ended DT and closed-ended insight problems. Taken together, our data validate previous findings. In single-dataset analysis, significant cluster activity triggered by DT was localized in the IPL, CUN, and MFG. During insightful conditions, activated clusters were found in the PreCG/IFG/MFG, PCUN/SPL, PG/AMG, and SFG/CG. Critically, DT provoked stronger activation in the IPL and LG/CUN relative to insight, an observation that implicates the predominant involvement of the DMN. Conversely, insight produced significant activated patterns in the PreCG/IFG, CG/MedFG, SPL/AG, and PG/AMG, all closely linked with cognitive control and affective functions. However, we detected no common activation pattern from the contrast and conjunction analyses. Thus, this meta-analysis implies that DT and insight may have independent neural roles in the dual-process theory.

#### AUTHOR CONTRIBUTIONS

Jiabao Lin, Lijun Ma, Jun Chen, and Lei Mo developed the study concept. Changyi Kuang and Jiawen Chen performed testing and data collection. Changyi Kuang, Huiyuan Huang, and Bingqing Jiao performed the data analysis and interpretation. Changyi Kuang, Jiawen Chen, Qiwen Lin, Yuyang Rao, Wenting Liu, and Yunpeng Zhu drafted the manuscript. Jiabao Lin, Lijun Ma, Yafei Shi, and Lei Mo provided critical revisions. All authors approved the final version of the manuscript for submission.

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#### CONFLICT OF INTEREST

The authors declared that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

#### DATA AVAILABILITY STATEMENT

The data for this project can be obtained with agreements from the corresponding authors. Researchers interested in access to the data

may contact Dr Jiabao Lin at [jiabaolingzucm@163.com](mailto:jiabaolingzucm@163.com). It can take some time to negotiate data use agreements and gain access to the data.

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## REFERENCES

- Abraham, A. (2014). Creative thinking as orchestrated by semantic processing vs. cognitive control brain networks. *Frontiers in Human Neuroscience*, 8, 95.
- Abraham, A., Pieritz, K., Thybusch, K., Rutter, B., Kröger, S., Schweckendiek, J., Stark, R., Windmann, S., & Hermann, C. (2012). Creativity and the brain: Uncovering the neural signature of conceptual expansion. *Neuropsychologia*, 50, 1906–1917.
- Abraham, A., Rutter, B., Bantini, T., & Hermann, C. (2018). Creative conceptual expansion: A combined fMRI replication and extension study to examine individual differences in creativity. *Neuropsychologia*, 118, 29–39.
- Allen, A. P., & Thomas, K. E. (2011). A dual process account of creative thinking. *Creativity Research Journal*, 23, 109–118.
- Aminoff, E. M., Kverega, K., & Bar, M. (2013). The role of the parahippocampal cortex in cognition. *Trends in Cognitive Sciences*, 17, 379–390.
- Amir, O., Biederman, I., Wang, Z., & Xu, X. (2015). Ha ha! Versus aha! A direct comparison of humor to nonhumorous insight for determining the neural correlates of mirth. *Cerebral Cortex*, 25, 1405–1413.
- Anderson, J. R., Anderson, J. F., Ferris, J. L., Fincham, J. M., & Jung, K. (2009). Lateral inferior prefrontal cortex and anterior cingulate cortex are engaged at different stages in the solution of insight problems. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 10799–10804.
- Andreasen, N. C., & Ramchandran, K. (2012). Creativity in art and science: Are there two cultures? *Dialogues in Clinical Neuroscience*, 14, 49–54.
- Andrews-Hanna, J. R. (2012). The Brain's default network and its adaptive role in internal mentation. *The Neuroscientist*, 18, 251–270.
- Aron, A. R., Fletcher, P. C., Bullmore, E. T., Sahakian, B. J., & Robbins, T. W. (2003). Stop-signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience*, 6, 115–116.
- Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, 8, 170–177.
- Avitia, M. J., & Kaufman, J. C. (2014). Beyond g and c: The relationship of rated creativity to long-term storage and retrieval (Glr). *Psychology of Aesthetics, Creativity, and the Arts*, 8, 293–302.
- Aziz-Zadeh, L., Kaplan, J. T., & Iacoboni, M. (2009). "Aha!": The neural correlates of verbal insight solutions. *Human Brain Mapping*, 30, 908–916.
- Aziz-Zadeh, L., Liew, S., & Dandekar, F. (2013). Exploring the neural correlates of visual creativity. *SCAN*, 8, 475–480.
- Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia*, 45, 2883–2901.
- Barr, N., Pennycook, G., Stolz, J. A., & Fugelsanga, J. A. (2014). Reasoned connections: A dual process perspective on creative thought. *Thinking & Reasoning*, 21(1), 61–75.
- Beaty, R. E., Benedek, M., Kaufman, S. B., & Silvia, P. J. (2015). Default and executive network coupling supports creative idea production. *Scientific Reports*, 5, 10964.
- Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends in Cognitive Sciences*, 20, 87–95.
- Beaty, R. E., Benedek, M., Wilkins, R. W., Jauk, E., Fink, A., Silvia, P. J., Hodges, D. A., Koschutnig, K., & Neubauer, A. C. (2014). Creativity and the default network: A functional connectivity analysis of the creative brain at rest. *Neuropsychologia*, 64, 92–98.
- Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., Fink, A., Qiu, J., Kwapil, T. R., Kane, M. J., & Silvia, P. J. (2018). Robust prediction of individual creative ability from brain functional connectivity. *Proceedings of the National Academy of Sciences of the United States of America*, 115, 1087–1092.
- Beaty, R. E., Christensen, A. P., Benedek, M., Silvia, P. J., & Schacter, D. L. (2017). Creative constraints: Brain activity and network dynamics underlying semantic interference during idea production. *NeuroImage*, 148, 189–196.
- Beaty, R. E., & Silvia, P. J. (2012). Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. *Psychology of Aesthetics, Creativity, and the Arts*, 6, 309–319.
- Beaty, R. E., & Silvia, P. J. (2013). Metaphorically speaking: Cognitive abilities and the production of figurative language. *Memory & Cognition*, 41, 255–267.
- Beaty, R. E., Thakral, P. P., Madore, K. P., Benedek, M., & Schacter, D. L. (2018). Core network contributions to remembering the past, imagining the future, and thinking creatively. *Journal of Cognitive Neuroscience*, 30, 1939–1951.
- Becker, M., Sommer, T., & Kühn, S. (2019a). Inferior frontal gyrus involvement during search and solution in verbal creative problem solving: A parametric fMRI study. *NeuroImage*, 206, 116294.
- Becker, M., Sommer, T., & Kühn, S. (2019b). Verbal insight revisited: fMRI evidence for early processing in bilateral insulae for solutions with AHA! Experience shortly after trial onset. *Human Brain Mapping*, 41, 30–45.
- Becker, M., Wiedemann, G., & Kühn, S. (2020). Quantifying insightful problem solving: A modified compound remote associates paradigm using lexical priming to parametrically modulate different sources of task difficulty. *Psychological Research*, 84, 528–545.
- Bendetowicz, D., Urbanski, M., Garcin, B. A., Foulon, C., Levy, R., Chemier, M. B., Rosso, C., de Schotten, M. T., & Volle, E. (2018). Two critical brain networks for generation and combination of remote associations. *Brain*, 141, 217–233.
- Benedek, M., Beaty, R., Jauk, E., Koschutnig, K., Fink, A., Silvia, P. J., Dunst, B., & Neubauer, A. C. (2014). Creating metaphors: The neural basis of figurative language production. *NeuroImage*, 90, 99–106.
- Benedek, M., Bergner, S., Könen, T., Fink, A., & Neubauer, A. C. (2011). EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. *Neuropsychologia*, 49, 3505–3511.
- Benedek, M., & Fink, A. (2019). Toward a neurocognitive framework of creative cognition: The role of memory, attention, and cognitive control. *Current Opinion in Behavioral Sciences*, 27, 116–122.
- Benedek, M., Franz, F., Heene, M., & Neubauer, A. C. (2012). Differential effects of cognitive inhibition and intelligence on creativity. *Personality and Individual Differences*, 53, 480–485.
- Benedek, M., & Jauk, E. (2018). Spontaneous and controlled processes in creative cognition. In *The Oxford handbook of spontaneous thought: Mind-wandering, creativity, dreaming, and clinical conditions*. Oxford University Press.
- Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., & Neubauer, A. C. (2014). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage*, 88, 125–133.
- Benedek, M., Jurisch, J., Koschutnig, K., Fink, A., & Beaty, R. E. (2020). Elements of creative thought: Investigating the cognitive and neural correlates of association and bi-association processes. *NeuroImage*, 210, 116586.
- Benedek, M., Könen, T., Neubauer, A. C., Reiter-Palmon, R., & Tinio, P. (2012). Associative abilities underlying creativity. *Psychology of Aesthetics, Creativity, and the Arts*, 6, 273–281.
- Benedek, M., Schües, T., Beaty, R. E., Jauk, E., Koschutnig, K., Fink, A., & Neubauer, A. C. (2017). To create or to recall original ideas: Brain

- processes associated with the imagination of novel object uses. *Cortex*, 99, 93–102.
- Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex*, 19, 2767–2796.
- Blackford, J. U., Buckholz, J. W., Avery, S. N., & Zald, D. H. (2009). A unique role for the human amygdala in novelty detection. *NeuroImage*, 50, 1188–1193.
- Blumenfeld, R. S., & Ranganath, C. (2016). Prefrontal cortex and long-term memory encoding: An integrative review of findings from neuropsychology and neuroimaging. *The Neuroscientist*, 13, 280–291.
- Boccia, M., Piccardi, L., Palermo, L., Nori, R., & Palmiero, M. (2015). Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Frontiers in Psychology*, 6, 1195.
- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108, 624–652.
- Brass, M., Derrfuss, J., Forstmann, B., & von Cramon, D. Y. (2005). The role of the inferior frontal junction area in cognitive control. *Trends in Cognitive Sciences*, 9, 314–316.
- Bressler, S. L., & Menon, V. (2010). Large-scale brain networks in cognition: Emerging methods and principles. *Trends in Cognitive Sciences*, 14, 277–290.
- Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The Brain's default network: Anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences*, 1124, 1–38.
- Bunge, S. A., & Souz, M. J. (2009). Executive function and higher-order cognition: Neuroimaging. In L. R. Square (Ed.), *Encyclopedia of Neurosciences*. Academic Press.
- Cabeza, R., Ciaramelli, E., Olson, I. R., & Moscovitch, M. (2008). The parietal cortex and episodic memory: An attentional account. *Nature Reviews Neuroscience*, 9, 613–625.
- Cairo, T. A., Liddle, P. F., Woodward, T. S., & Ngan, E. T. C. (2004). The influence of working memory load on phase specific patterns of cortical activity. *Cognitive Brain Research*, 21, 377–387.
- Carter, C. S., Macdonald, A. M., Botvinick, M., Ross, L. L., Stenger, V. A., Noll, D., & Cohen, J. D. (2000). Parsing executive processes: Strategic vs. evaluative functions of the anterior cingulate cortex. *Proceeding National Academy of Sciences of the United States of America*, 97, 1944–1948.
- Cartwright, M., Clark-Carter, D., Ellis, S. J., & Matthews, C. (2004). Temporal lobe epilepsy and creativity: A model of association. *Creativity Research Journal*, 16, 27–34.
- Chen, Q. L., Xu, T., Yang, W. J., Li, Y. D., Sun, J. Z., Wang, K. C., Beaty, R. E., Zhang, Q. L., Zuo, X. N., & Qiu, J. (2015). Individual differences in verbal creative thinking are reflected in the precuneus. *Neuropsychologia*, 75, 441–449.
- Chrysikou, E. G., & Thompson-Schill, S. L. (2011). Dissociable brain states linked to common and creative object use. *Human Brain Mapping*, 32, 665–675.
- Cogdell-Brooke, L. S., Sowden, P. T., Violante, I. R., & Thompson, H. E. (2020). A meta-analysis of functional magnetic resonance imaging studies of divergent thinking using activation likelihood estimation. *Human Brain Mapping*, 41, 5057–5077.
- Cropley, A. (2006). In praise of convergent thinking. *Creativity Research Journal*, 18, 391–404.
- Curtis, C. E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *Trends in Cognitive Sciences*, 7, 415–423.
- Danek, A. H., & Flanagin, V. L. (2019). Cognitive conflict and restructuring: The neural basis of two core components of insight. *AIMS Neuroscience*, 6(2), 60–84.
- Derrfuss, J., Brass, M., Neumann, J., & von Cramon, D. Y. (2005). Involvement of the inferior frontal junction in cognitive control: Meta-analyses of switching and Stroop studies. *Human Brain Mapping*, 25, 22–34.
- Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological Bulletin*, 136, 822–848.
- Dobbins, I. G., Rice, H. J., Wagner, A. D., & Schacter, D. L. (2003). Memory orientation and success: Separable neurocognitive components underlying episodic recognition. *Neuropsychologia*, 41, 318–333.
- Doyle, C. L. (2017). Creative flow as a unique cognitive process. *Frontiers in Psychology*, 8, 1348.
- Düzel, E., Habib, R., Rotte, M., Guderian, S., Tulving, E., & Heinze, H. (2003). Human hippocampal and Parahippocampal activity during visual associative recognition memory for spatial and nonspatial stimulus configurations. *The Journal of Neuroscience*, 23, 9439–9444.
- Eickhoff, S. B., Bzdok, D., Laird, A. R., Kurth, F., & Fox, P. T. (2012). Activation likelihood estimation meta-analysis revisited. *NeuroImage*, 59, 2349–2361.
- Eickhoff, S. B., Laird, A. R., Fox, P. M., Lancaster, J. L., & Fox, P. T. (2016). Implementation errors in the GingerALE software: Description and recommendations. *Human Brain Mapping*, 38, 7–11.
- Eickhoff, S. B., Laird, A. R., Grefkes, C., Wang, L. E., Zilles, K., & Fox, P. T. (2009). Coordinate-based activation likelihood estimation meta-analysis of neuroimaging data: A random-effects approach based on empirical estimates of spatial uncertainty. *Human Brain Mapping*, 30, 2907–2926.
- Ellamil, M., Dobson, C., Beeman, M., & Christoff, K. (2012). Evaluative and generative modes of thought during the creative process. *NeuroImage*, 59, 1783–1794.
- Erhard, K. Q., Kessler, F., Neumann, N., Ortheil, H. J., & Lotze, M. (2014). Professional training in creative writing is associated with enhanced 2 fronto-striatal activity in a literary text continuation task. *NeuroImage*, 100, 15–23.
- Ernst, M., & Koeletz, K. E. (2009). Cerebral maturation in adolescence: Behavioral vulnerability. *Encephale*, 35, S182–S189.
- Evans, J. S. B. T. (2003). In two minds: Dual-process accounts of reasoning. *Trends in Cognitive Sciences*, 7, 454–459.
- Evans, J. S. B. T. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology*, 59, 255–278.
- Evans, J. S. B. T. (2011). Dual-process theories of reasoning: Contemporary issues and developmental applications. *Developmental Review*, 31, 86–102.
- Evans, J. S. B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science*, 8, 223–241.
- Fink, A., Benedek, M., Koschutnig, K., Pirker, E., Berger, E., Meister, S., Neubauer, A. C., Papousek, I., & Weiss, E. M. (2015). Training of verbal creativity modulates brain activity in regions associated with language- and memory-related demands. *Human Brain Mapping*, 36, 4104–4115.
- Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., Neuper, C., Ebner, F., & Neubauer, A. C. (2009). The creative brain: Investigation of brain activity during creative problem solving by means of EEG and fMRI. *Human Brain Mapping*, 30, 734–748.
- Fink, A., Grabner, R. H., Gebauer, D., Reishofer, G., Koschutnig, K., & Ebner, F. (2010). Enhancing creativity by means of cognitive stimulation: Evidence from an fMRI study. *NeuroImage*, 52, 1687–1695.
- Fink, A., Koschutnig, K., Benedek, M., Reishofer, G., Ischebeck, A., Weiss, E. M., & Ebner, F. (2011). Stimulating creativity via the exposure to other people's ideas. *Human Brain Mapping*, 33, 2603–2610.
- Fink, A., Koschutnig, K., Hutterer, L., Steiner, E., Benedek, M., Weber, B., Reishofer, G., Papousek, I., & Weiss, E. M. (2013). Gray matter density in relation to different facets of verbal creativity. *Brain Structure & Function*, 219, 1263–1269.
- Forthmann, B., Jendryczko, D., Scharfen, J., Kleinkorres, R., Benedek, M., & Holling, H. (2019). Creative ideation, broad retrieval ability, and processing speed: A confirmatory study of nested cognitive abilities. *Intelligence*, 75, 59–72.

- Gabora, L. (2010). Revenge of the "Neurds": Characterizing creative thought in terms of the structure and dynamics of memory. *Creativity Research Journal*, 22, 1–13.
- Gilhooly, K. J., Fioratou, E., Anthony, S. H., & Wynn, V. (2007). Divergent thinking: Strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology*, 98, 611–625.
- Girardeau, G., Inema, I., & Buzsáki, G. (2017). Reactivations of emotional memory in the hippocampus-amygdala system during sleep. *Nature Neuroscience*, 20, 1634–1642.
- Goel, V., & Vartanian, O. (2005). Dissociating the roles of right ventral lateral and dorsal lateral prefrontal cortex in generation and maintenance of hypotheses in set-shift problems. *Cerebral Cortex*, 15, 1170–1177.
- Gonen-Yaacovi, G., de Souza, L. C., Levy, R., Urbanski, M., Josse, G., & Volle, E. (2013). Rostral and caudal prefrontal contribution to creativity: A meta-analysis of functional imaging data. *Frontiers in Human Neuroscience*, 7, 465.
- Green, A. E., Cohen, M. S., Raab, H. A., Yedibalian, C. G., & Gray, J. R. (2014). Frontopolar activity and connectivity support dynamic conscious augmentation of creative state. *Human Brain Mapping*, 36, 923–934.
- Gronchi, G., & Giovannelli, F. (2018). Dual process theory of thought and default mode network: A possible neural foundation of Fast Thinking. *Frontiers in Psychology*, 9, 1237.
- Guilford, J. P. (1967). *The nature of human intelligence*. McGraw-Hill Book Co.
- Hao, X., Cui, S., Li, W., Yang, W., Qiu, J., & Zhang, Q. (2013). Enhancing insight in scientific problem solving by highlighting the functional features of prototypes: An fMRI study. *Brain Research*, 1534, 46–54.
- Heinonen, J., Numminen, J., Hlushchuk, Y., Antell, H., Taatila, V., Suomala, J., & Stamatakis, E. A. (2016). Default mode and executive networks areas: Association with the serial order in divergent thinking. *PLoS One*, 11, e162234.
- Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of topdown attentional control. *Nature*, 3(3), 284–291.
- Howard-Jones, P. A., Blakemore, S., Samuel, E. A., Summers, I. R., & Claxton, G. (2005). Semantic divergence and creative story generation: An fMRI investigation. *Cognitive Brain Research*, 25, 240–250.
- Huang, F., Fan, J., & Luo, J. (2015). The neural basis of novelty and appropriateness in processing of creative chunk decomposition. *NeuroImage*, 113, 122–132.
- Huang, F., Tang, S., Sun, P., & Luo, J. (2018). Neural correlates of novelty and appropriateness processing in externally induced constraint relaxation. *NeuroImage*, 172, 381–389.
- Hunkin, N. M., Mayes, A. R., Gregory, L. J., Nicholas, A. K., Nunn, J. A., Brammer, M. J., Bullmore, E. T., & Williams, S. C. R. (2002). Novelty-related activation within the medial temporal lobes. *Neuropsychologia*, 40, 1456–1464.
- Igelström, K. M., & Graziano, M. S. A. (2017). The inferior parietal lobule and temporoparietal junction: A network perspective. *Neuropsychologia*, 105, 70–83.
- Ishibashi, R., Lambon Ralph, M. A., Saito, S., & Pobric, G. (2011). Different roles of lateral anterior temporal lobe and inferior parietal lobule in coding function and manipulation tool knowledge: Evidence from an rTMS study. *Neuropsychologia*, 49, 1128–1135.
- Ivancovsky, T., Kleinmintz, O., Lee, J., Kurman, J., & Shamay Tsoory, S. G. (2018). The neural underpinnings of cross-cultural differences in creativity. *Human Brain Mapping*, 39, 4493–4508.
- Jauk, E. (2019). A bio-psycho-behavioral model of creativity. *Current Opinion in Behavioral Sciences*, 27, 1–6.
- Jauk, E., Neubauer, A. C., Dunst, B., Fink, A., & Benedek, M. (2015). Gray matter correlates of creative potential: A latent variable voxel-based morphometry study. *NeuroImage*, 111, 312–320.
- Jung, R. E. (2013). The structure of creative cognition in the human brain. *Frontiers in Human Neuroscience*, 7, 330.
- Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., Reber, P. J., Kounios, J., & Stanislas, D. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biology*, 2, E97.
- Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus and Giroux.
- Kim, H. (2015). Default network activation during episodic and semantic memory retrieval: A selective meta-analytic comparison. *Neuropsychologia*, 80, 35–46.
- Kizilirmak, J. M., Schott, B. H., Thuerich, H., Sweeney-Reed, C. M., Richter, A., Folta-Schoofs, K., & Richardson-Klavehn, A. (2019). Learning of novel semantic relationships via sudden comprehension is associated with a hippocampus-independent network. *Consciousness and Cognition*, 69, 113–132.
- Kizilirmak, J. M., Thuerich, H., Folta-Schoofs, K., Björn, H. S., & Richardson-Klavehn, A. (2016). Neural correlates of learning from induced insight: A case for reward-based episodic encoding. *Frontiers in Psychology*, 7, 1693.
- Kjaer, T. W., Nowak, M., Kjaer, K. W., Lou, A. R., & Lou, H. C. (2001). Precuneus-prefrontal activity during awareness of visual verbal stimuli. *Consciousness and Cognition*, 10, 356–365.
- Kleibeuker, S. W., Koolschijn, P. C. M. P., Jolles, D. D., De Dreu, C. K. W., & Crone, E. A. (2013). The neural coding of creative idea generation across adolescence and early adulthood. *Frontiers in Human Neuroscience*, 7, 905.
- Kleinmintz, O. M., Abecasis, D., Tauber, A., Geva, A., Chistyakov, A. V., Kreinin, I., Klein, E., & Shamay-Tsoory, S. G. (2017). Participation of the left inferior frontal gyrus in human originality. *Brain Structure and Function*, 223, 329–341.
- Koechlin, E., & Summerfield, C. (2007). An information theoretical approach to prefrontal executive function. *Trends in Cognitive Sciences*, 11, 229–235.
- Kounios, J., & Beeman, M. (2009). The aha! Moment: The cognitive neuroscience of insight. *Current Directions in Psychological Science*, 18(4), 210–216.
- Kounios, J., & Beeman, M. (2014). The cognitive neuroscience of insight. *Annual Review of Psychology*, 65, 71–93.
- Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. I., Subramaniam, K., Parrish, T. B., & Jung-Beeman, M. (2006). The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science*, 17, 882–890.
- Laird, A. R., Robinson, J. L., McMillan, K. M., Tordesillas-Gutiérrez, D., Moran, S. T., Gonzales, S. M., Ray, K. L., Franklin, C., Glahn, D. C., Fox, P. T., & Lancaster, J. L. (2010). Comparison of the disparity between Talairach and MNI coordinates in functional neuroimaging data: Validation of the Lancaster transform. *NeuroImage*, 51, 677–683.
- Lancaster, J. L., Laird, A. R., Fox, P. M., Glahn, D. E., & Fox, P. T. (2005). Automated analysis of meta-analysis networks. *Human Brain Mapping*, 25, 174–184.
- Lancaster, J. L., Tordesillas-Gutiérrez, D., Martinez, M., Salinas, F., Evans, A., Zilles, K., Mazziotta, J. C., & Fox, P. T. (2007). Bias between MNI and Talairach coordinates analyzed using the ICBM-152 brain template. *Human Brain Mapping*, 28, 1194–1205.
- Langner, R., & Camilleri, J. A. (2021). Meta-Analytic Connectivity Modeling (MACM): A Tool for Assessing Region-Specific Functional Connectivity Patterns in Task-Constrained States.
- Langner, R., Rottschy, C., Laird, A. R., Fox, P. T., & Eickhoff, S. B. (2014). Meta-analytic connectivity modeling revisited: Controlling for activation base rates. *NeuroImage*, 99, 559–570.
- Lebouillier, N., & Marks, D. F. (2003). Mental imagery and creativity: A meta-analytic review study. *British Journal of Psychology*, 94, 29–44.
- Li, W., Li, G., Ji, B., Zhang, Q., & Qiu, J. (2019). Neuroanatomical correlates of creativity: Evidence from voxel-based morphometry. *Frontiers in Psychology*, 10, 155.

- Li, W., Wen, Q., Huaigui, L., Lingzhong, F., Jiaojian, W., Tianzi, J., & Yu, C. (2013). Subregions of the human superior frontal gyrus and their connections. *NeuroImage*, *78*, 46–58.
- Liakakis, G., Nickel, J., & Seitz, R. J. (2011). Diversity of the inferior frontal gyrus—A meta-analysis of neuroimaging studies. *Behavioural Brain Research*, *225*, 341–347.
- Lin, J., Cui, X., Dai, X., Chen, Y., & Mo, L. (2018). Neural correlates of creative insight: Amplitude of low-frequency fluctuation of resting-state brain activity predicts creative insight. *PLoS One*, *13*, e0203071.
- Lin, J., Wen, X., Cui, X., Xiang, Y., Xie, J., Chen, Y., Huang, R., & Mo, L. (2020). Common and specific neural correlates underlying insight and ordinary problem solving. *Brain Imaging and Behavior*, *15*, 1374–1387.
- Lin, W., Hsu, K., Chen, H., & Wang, J. (2011). The relations of gender and personality traits on different creativities: A dual-process theory account. *Psychology of Aesthetics, Creativity, and the Arts*, *6*, 112–123.
- Lin, W., & Lien, Y. (2013). The different role of working memory in open-ended versus closed-ended creative problem solving: A dual-process theory account. *Creativity Research Journal*, *25*, 85–96.
- Liotti, M., Woldorff, M. G., Perez, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*, 701–711.
- Ludmer, R., Dudai, Y., & Rubin, N. (2011). Uncovering camouflage: Amygdala activation predicts long-term memory of induced perceptual insight. *Neuron*, *69*, 1002–1014.
- Luks, T. L., Simpson, G. V., Feiwel, R. J., & Miller, W. L. (2002). Evidence for anterior cingulate cortex involvement in monitoring preparatory attentional set. *NeuroImage*, *17*, 792–802.
- Luo, J., Li, W., Qiu, J., Wei, D., Liu, Y., Zhang, Q., & Kilner, J. (2013). Neural basis of scientific innovation induced by heuristic prototype. *PLoS One*, *8*, e49231.
- Luo, J., & Niki, K. (2003). Function of hippocampus in insight of problem solving. *Hippocampus*, *13*, 316–323.
- Luo, J., Niki, K., & Knoblich, G. (2006). Perceptual contributions to problem solving: Chunk decomposition of Chinese characters. *Brain Research Bulletin*, *70*, 430–443.
- Luo, J., Niki, K., & Phillips, S. (2004a). The function of the anterior cingulate cortex (ACC) in the insightful solving of puzzles: The ACC is activated less when the structure of the puzzle is known. *Journal of Psychology in Chinese Societies*, *5*(2), 195–213.
- Luo, J., Niki, K., & Phillips, S. (2004b). Neural correlates of the ‘aha! Reaction’. *Neuroreport*, *15*, 2013–2017.
- MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, *288*, 1835–1838.
- MacGregor, J. N., Ormerod, T. C., & Chronicle, E. P. (2001). Information processing and insight: A process model of performance on the nine-dot and related problems. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *27*, 176–201.
- Madore, K. P., Thakral, P. P., Beaty, R. E., Addis, D. R., & Schacter, D. L. (2017). Neural mechanisms of episodic retrieval support divergent creative thinking. *Cerebral Cortex*, *29*, 150–166.
- Mai, X., Luo, J., Wu, J., & Luo, Y. (2004). Aha effects in a guessing riddle task: An event-related potential study. *Human Brain Mapping*, *22*, 261–270.
- Marron, T. R., Lerner, Y., Berant, E., Kinreich, S., Shapira-Lichter, I., Hendler, T., & Faust, M. (2018). Chain free association, creativity, and the default mode network. *Neuropsychologia*, *118*, 40–58.
- Mashal, N., Faust, M., Hendler, T., & Jung-Beeman, M. (2007). An fMRI investigation of the neural correlates underlying the processing of novel metaphoric expressions. *Brain and Language*, *100*, 115–126.
- Matheson, H. E., & Kenett, Y. N. (2020). The role of the motor system in generating creative thoughts. *NeuroImage*, *213*, 116697.
- Mayseless, N., Eran, A., & Shamay-Tsoory, S. G. (2015). Generating original ideas: The neural underpinning of originality. *NeuroImage*, *116*, 232–239.
- Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*, *69*, 220–232.
- Milham, M. P., Banich, M. T., Claus, E. D., & Cohen, N. J. (2003). Practice-related effects demonstrate complementary roles of anterior cingulate and prefrontal cortices in attentional control. *NeuroImage*, *18*, 483–493.
- Müller, V. I., Cieslik, E. C., Laird, A. R., Fox, P. T., Radua, J., Mataix-Cols, D., Tench, C. R., Yarkoni, T., Nichols, T. E., Turkeltaub, P. E., Wager, T. D., & Eickhoff, S. B. (2018). Ten simple rules for neuroimaging meta-analysis. *Neurosciences & Biobehavioral Reviews*, *84*, 151–161.
- Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O’Reilly, R. C. (2011). A unified framework for inhibitory control. *Trends in Cognitive Sciences*, *15*, 453–459.
- Nee, D. E., Brown, J. W., Askren, M. K., Berman, M. G., Demiralp, E., Krawitz, A., & Jonides, J. (2013). A meta-analysis of executive components of working memory. *Cerebral Cortex*, *23*, 264–282.
- Noonan, K. A., Jefferies, E., Corbett, F., & Ralph, M. A. L. (2010). Elucidating the nature of deregulated semantic cognition in semantic aphasia: Evidence for the roles of prefrontal and temporo-parietal cortices. *Journal of Neuroscience*, *22*, 1597–1613.
- Ogawa, T., Aihara, T., Shimokawa, T., & Yamashita, O. (2018). Large-scale brain network associated with creative insight: Combined voxel-based morphometry and resting-state functional connectivity analyses. *Scientific Reports*, *8*, 6477.
- Paek, S. H., Alabbasi, A. M., Acar, S., & Runco, M. A. (2021). Is more time better for divergent thinking? A meta-analysis of the time-on-task effect on divergent thinking. *Thinking Skills and Creativity*, *41*, 100894.
- Page, M. J., McKenzie, J. E., Patrick, M. B., Isabelle, B., Tammy, C. H., Mulrow, C. D., Larissa, S., Jennifer, M. T., Elie, A. A., Sue, E. B., Roger, C., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Systematic Reviews*, *10*, 89.
- Pang, J., Tang, X., Niki, K., & Luo, J. (2009). Brain activities related to the Chinese character chunking tasks: An fMRI study. *IEEE*, *6*, 32–37.
- Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: From a ‘low road’ to ‘many roads’ of evaluating biological significance. *Nature Reviews Neuroscience*, *11*, 773–783.
- Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89.
- Qiu, J., Li, H., Jou, J., Liu, J., Luo, Y., Feng, T., Wu, Z., & Zhang, Q. (2010). Neural correlates of the “aha” experiences: Evidence from an fMRI study of insight problem solving. *Cortex*, *46*, 397–403.
- Radel, R., Karen, D., Marion, F., & Arne, D. (2014). The role of (dis)inhibition in creativity: Decreased inhibition improves idea generation. *Cognition*, *134*, 110–120.
- Raichle, M. E. (2015). The Brain’s default mode network. *Annual Review of Neuroscience*, *38*, 433–447.
- Redish, A. D. (2001). The hippocampal debate: Are we asking the right questions? *Behavioural Brain Research*, *127*, 81–98.
- Robinson, J. L., Laird, A. R., Glahn, D. C., Lovallo, W. R., & Fox, P. T. (2010). Metaanalytic connectivity modeling: Delineating the functional connectivity of the human amygdala. *Human Brain Mapping*, *31*, 173–184.
- Rutishauser, U., Mamelak, A. N., & Schuman, E. M. (2006). Single-trial Learning of novel stimuli by individual neurons of the human hippocampus-amygdala complex. *Neuron*, *49*, 805–813.
- Schuck, N. W., Gaschler, R., Wenke, D., Heinze, J., Frensch, P. A., Haynes, J. D., & Reverber, C. (2015). Medial prefrontal cortex predicts internally driven strategy shifts. *Neuron*, *86*, 331–340.
- Schwartz, C. E., Wright, C. I., Shin, L. M., Kagan, J., Whalen, P. J., McMullin, K. G., & Rauch, S. L. (2003). Differential Amygdalar response to novel versus newly familiar neutral faces: A functional MRI probe developed for studying inhibited temperament. *Society of Biological Psychiatry*, *53*, 854–862.

- Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., Reiss, A. L., & Greicius, M. D. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *The Journal of Neurosciences*, 27(9), 2349–2356.
- Seger, C. A., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. E. (2000). Functional magnetic resonance imaging evidence for right-hemisphere involvement in processing unusual semantic relationships. *Neuropsychology*, 14, 361–369.
- Shah, C., Erhard, K., Ortheil, H., Kaza, E., Kessler, C., & Lotze, M. (2011). Neural correlates of creative writing: An fMRI study. *Human Brain Mapping*, 34, 1088–1101.
- Shamay-Tsoory, S. G., Adler, N., Aharon-Peretz, J., Perry, D., & Maysel, N. (2011). The origins of originality: The neural bases of creative thinking and originality. *Neuropsychologia*, 49, 178–185.
- Shaw, P., Greenstein, D., Lerch, J., Clasen, L., Lenroot, R., Gogtay, N., Evans, A., Rapoport, J., & Giedd, J. (2006). Intellectual ability and cortical development in children and adolescents. *Nature*, 440, 676–679.
- Shen, W., Tong, Y., Li, F., Yuan, Y., Hommel, B., Liu, C., & Luo, J. (2018). Tracking the neurodynamics of insight: A meta-analysis of neuroimaging studies. *Biological Psychology*, 138, 189–198.
- Shen, W., Yuan, Y., Liu, C., & Luo, J. (2016). In search of the 'aha!' Experience: Elucidating the emotionality of insight problem-solving. *British Journal of Psychology*, 107, 281–298.
- Shen, W., Yuan, Y., Liu, C., & Luo, J. (2017). The roles of the temporal lobe in creative insight: An integrated review. *Thinking & Reasoning*, 23, 321–375.
- Shen, W., Yuan, Y., Liu, C., Zhang, X., Luo, J., & Gong, Z. (2016). Is creative insight task-specific? A coordinate-based meta-analysis of neuroimaging studies on insightful problem solving. *International Journal of Psychophysiology*, 110, 81–90.
- Silvia, P. J., Beaty, R. E., & Nusbaum, E. C. (2013). Verbal fluency and creativity: General and specific contributions of broad retrieval ability (gr) factors to divergent thinking. *Intelligence*, 41, 328–340.
- Sinityn, D. O., Bakulin, I. S., Poydasheva, A. G., Legostaeva, L. A., Kremneva, E. I., Lagoda, D. Y., Chernyavskiy, A. Y., Medyantsev, A. A., Suponeva, N. A., & Piradov, M. A. (2020). Brain activations and functional connectivity patterns associated with insight-based and analytical anagram solving. *Behavioral Sciences*, 10, 170.
- Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin*, 119, 3–22.
- Smith, A. P. R., Henson, R. N. A., Dolan, R. J., & Rugg, M. D. (2004). fMRI correlates of the episodic retrieval of emotional contexts. *NeuroImage*, 22, 868–878.
- Smith, E. R., & DeCoster, J. (2000). Dual-process models in social and cognitive Psychology: Conceptual integration and links to underlying memory systems. *Personality and Social Psychology Review*, 4, 108–131.
- Sowden, P. T., Pringle, A., & Gabora, L. (2015). The shifting sands of creative thinking: Connections to dual-process theory. *Thinking & Reasoning*, 21, 40–60.
- Sprugnoli, G., Rossi, S., Emmendorfer, A., Rossi, A., Liew, S., Tatti, E., di Lorenzo, G., Pascual-Leone, A., & Santarnecchi, E. (2017). Neural correlates of Eureka moment. *Intelligence*, 62, 99–118.
- Squire, L. R., Stark, C. E. L., & Clark, R. E. (2004). The medial temporal lobe. *Annual Review of Neuroscience*, 27, 279–306.
- Stanovich, K. E., & West, R. F. (2000). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences*, 23, 645–665.
- Sternberg, R. J., & Lubart, T. I. (1996). Investing in creativity. *American Psychologist*, 51, 677–688.
- Subramaniam, K., Faust, M., Beeman, M., & Mashal, N. (2012). The repetition paradigm: Enhancement of novel metaphors and suppression of conventional metaphors in the left inferior parietal lobe. *Neuropsychologia*, 50, 2705–2719.
- Subramaniam, K., Kounios, J., Parrish, T. B., & Jung-Beeman, M. (2009). A brain mechanism for facilitation of insight by positive affect. *Journal of Cognitive Neuroscience*, 21, 415–432.
- Sun, J., Chen, Q., Zhang, Q., Li, Y., Li, H., Wei, D., Yang, W., & Qiu, J. (2016). Training your brain to be more creative: Brain functional and structural changes induced by divergent thinking training. *Human Brain Mapping*, 37, 3375–3387.
- Sun, J., Shi, L., Chen, Q., Yang, W., Wei, D., Zhang, J., Zhang, Q., & Qiu, J. (2019). Openness to experience and psychophysiological interaction patterns during divergent thinking. *Brain Imaging and Behavior*, 13, 1580–1589.
- Tang, X., Pang, J., Nie, Q., Conci, M., Luo, J., & Luo, J. (2015). Probing the cognitive mechanism of mental representational change during chunk decomposition: A parametric fMRI study. *Cerebral Cortex*, 26, 2991–2999.
- Terai, H., Miwa, K., & Asami, K. (2013). fMRI study in insight problem solving using Japanese remote associates test based on semantic chunk decomposition. *Proceedings of the Annual Meeting of the Cognitive Science Society*, 35, 3516–3521.
- Tian, F., Tu, S., Qiu, J., Lv, J. Y., Wei, D. T., Su, Y. H., & Zhang, Q. L. (2011). Neural correlates of mental preparation for successful insight problem solving. *Behavioural Brain Research*, 216, 626–630.
- Tik, M., Sladky, R., Luft, C. D. B., Willinger, D., Hoffmann, A., Banissy, M. J., Bhattacharya, J., & Windischberger, C. (2018). Ultra-high-field fMRI insights on insight: Neural correlates of the aha!-moment. *Human Brain Mapping*, 39, 3241–3252.
- Tong, D., Zhu, H., Li, W., Yang, W., Qiu, J., & Zhang, Q. (2013). Brain activity in using heuristic prototype to solve insightful problems. *Behavioural Brain Research*, 253, 139–144.
- Tsujii, T., Sakatani, K., Masuda, S., Akiyama, T., & Watanabe, S. (2011). Evaluating the roles of the inferior frontal gyrus and superior parietal lobule in deductive reasoning: An rTMS study. *NeuroImage*, 58, 640–646.
- Turkeltaub, P. E., Eden, G. F., Jones, K. M., & Zeffiro, T. A. (2002). Meta-analysis of the functional neuroanatomy of single-word Reading: Method and validation. *NeuroImage*, 16, 765–780.
- Turkeltaub, P. E., Eickhoff, S. B., Laird, A. R., Fox, M., Wiener, M., & Fox, P. (2012). Minimizing within-experiment and within-group effects in activation likelihood estimation meta-analyses. *Human Brain Mapping*, 33, 1–13.
- Uddin, L. Q. (2017). Functions of the salience network. In *Salience network of the human brain* (pp. 11–66). Academic Press.
- van Strien, N. M., Cappaert, N. L. M., & Witter, M. P. (2009). The anatomy of memory: An interactive overview of the parahippocampal-hippocampal network. *Nature Reviews Neuroscience*, 10(4), 272–282.
- Vartanian, O., Beatty, E. L., Smith, I., Blackler, K., Lam, Q., & Forbes, S. (2018). One-way traffic: The inferior frontal gyrus controls brain activation in the middle temporal gyrus and inferior parietal lobule during divergent thinking. *Neuropsychologia*, 118, 68–78.
- Vartanian, O., Jobidon, M. E., Bouak, F., Nakashima, A., Smith, I., Lam, Q., & Cheung, B. (2013). Working memory training is associated with lower prefrontal cortex activation in a divergent thinking task. *Neuroscience*, 236, 186–194.
- Vartanian, O., Martindale, C., & Kwiatkowski, J. (2007). Creative potential, attention, and speed of information processing. *Personality and Individual Differences*, 43, 1470–1480.
- Vatansver, D., Menon, D. K., & Stamatakis, E. A. (2017). Default mode contributions to automated information processing. *Proceedings of the National Academy of Sciences of the United States of America*, 114, 12821–12826.
- Vogt, B. A., & Laureys, S. (2005). Posterior cingulate, precuneal and retrosplenial cortices: Cytology and components of the neural network correlates of consciousness. *Progress in Brain Research*, 150, 205–217.
- Wagner, A. D., Maril, A., Bjork, R. A., & Schacter, D. L. (2001). Prefrontal contributions to executive control: fMRI evidence for functional distinctions within lateral prefrontal cortex. *NeuroImage*, 14, 1337–1347.

- Wang, T., Zhang, Q., Li, H., Qiu, J., Tu, S., & Yu, C. (2009). The time course of Chinese riddles solving: Evidence from an ERP study. *Behavioral Brain Research, 199*, 278–282.
- Wang, X., He, Y., Lu, K., Deng, C., Qiao, X., & Hao, N. (2019). How does the embodied metaphor affect creative thinking? *NeuroImage, 202*, 116114.
- Wei, D., Yang, J., Li, W., Wang, K., Zhang, Q., & Qiu, J. (2014). Increased resting functional connectivity of the medial prefrontal cortex in creativity by means of cognitive stimulation. *Cortex, 51*, 92–102.
- Weisberg, R. W. (2013). On the "demystification" of insight: A critique of neuroimaging studies of insight. *Creativity Research Journal, 25*, 1–14.
- Wieth, M., & Zacks, R. T. (2011). Time of day effects on problem solving: When the non-optimal is optimal. *Thinking & Reasoning, 17*, 387–401.
- Wiley, J., & Jarosz, A. F. (2012). Working memory capacity, attentional focus, and problem solving. *Current Directions in Psychological Science, 21*, 258–262.
- Woodward, T. S., Meier, B., Cairo, T. A., & Ngan, E. T. C. (2006). Temporoprefrontal coordination increases when semantic associations are strongly encoded. *Neuropsychologia, 44*, 2308–2314.
- Wu, H., Luo, Y., & Feng, C. (2016). Neural signatures of social conformity: A coordinate-based activation likelihood estimation meta-analysis of functional brain imaging studies. *Neuroscience & Biobehavioral Reviews, 71*, 101–111.
- Wu, L., Knoblich, G., & Luo, J. (2013). The role of chunk tightness and chunk familiarity in problem solving: Evidence from ERPs and fMRI. *Human Brain Mapping, 34*, 1173–1186.
- Wu, X., Yang, W., Tong, D., Sun, J., Chen, Q., Wei, D., Zhang, Q., Zhang, M., & Qiu, J. (2015). A meta-analysis of neuroimaging studies on divergent thinking using activation likelihood estimation. *Human Brain Mapping, 36*, 2703–2718.
- Yang, J., Mecklinger, A., Xu, M., Zhao, Y., & Weng, A. X. (2008). Decreased parahippocampal activity in associative priming: Evidence from an event-related fMRI study. *Learning and Memory, 15*, 710–730.
- Yang, Y., & Wang, J. (2017). From structure to behavior in basolateral amygdala-hippocampus circuits. *Frontiers in Neural Circuits, 11*, 86.
- Yu, F., Zhang, J., Fan, J., Luo, J., & Zhang, W. (2019). Hippocampus and amygdala: An insight-related network involved in metaphorical solution to mental distress problem. *Cognitive, Affective, & Behavioral Neuroscience, 19*, 1022–1035.
- Zabelina, D. L., & Andrews-Hanna, J. R. (2016). Dynamic network interactions supporting internally-oriented cognition. *Current Opinion in Neurobiology, 40*, 86–93.
- Zabelina, D. L., & Ganis, G. (2018). Creativity and cognitive control: Behavioral and ERP evidence that divergent thinking, but not real-life creative achievement, relates to better cognitive control. *Neuropsychologia, 118*, 20–28.
- Zhang, H., Liu, J., & Zhang, Q. (2014). Neural representations for the generation of inventive conceptions inspired by adaptive feature optimization of biological species. *Cortex, 50*, 162–173.
- Zhang, L., Qiao, L., Che, X., Xu, M., Chen, Q., Yang, W., Qiu, J., & Yang, D. (2019). Volumetric evidence of the mediating role of mental imagery in episodic memory effect on divergent thinking. *Current Psychology, 39*, 1138–1148.
- Zhang, L., Qiao, L., Chen, Q., Yang, W., Xu, M., Yao, X., Qiu, J., & Yang, D. (2016). Gray matter volume of the lingual gyrus mediates the relationship between inhibition function and divergent thinking. *Frontiers in Psychology, 7*, 1532.
- Zhang, M., Tian, F., Wu, X., Liao, S., & Qiu, J. (2011). The neural correlates of insight in Chinese verbal problems: An event related-potential study. *Brain Research Bulletin, 84*, 210–214.
- Zhang, W., Sjoerds, Z., & Hommel, B. (2020). Metacognition of human creativity: The neurocognitive mechanisms of convergent and divergent thinking. *NeuroImage, 210*, 116572.
- Zhao, Q., Zhou, Z., Xu, H., Chen, S., Xu, F., Fan, W., Han, L., & Antonietti, A. (2013). Dynamic neural network of insight: A functional magnetic resonance imaging study on solving Chinese 'Chengyu' riddles. *PLoS One, 8*, e59351.
- Zhao, Q., Zhou, Z., Xu, H., Fan, W., & Han, L. (2014). Neural pathway in the right hemisphere underlies verbal insight problem solving. *Neuroscience, 256*, 334–341.
- Zhou, Z., Xu, H., Zhao, Q., Zhao, L., & Liao, M. (2011). The processing of novel semantic association in Chinese: Converging evidence from behavior and fMRI studies. *2011 4th International Congress on Image and Signal Processing*, pp. 1588–1592.

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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