

# Creativity, Self-Generated Thought, and the Brain's Default Network

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## THE DEFAULT NETWORK AND ITS ROLE IN SELF-GENERATED THOUGHT

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Early neuroimaging research focused largely on localization of brain function, aiming to identify specific regions underlying various cognitive processes. This seminal research, along with the field of neuropsychology, provided a wealth of knowledge on how individual brain regions support various cognitive functions. More recently, neuroscientists have shifted focus to studying the interaction of brain regions (i.e., networks; Sporns, 2014). A majority of brain network research has employed resting-state functional magnetic resonance imaging (fMRI), a technique that measures spontaneous fluctuations in blood flow in the brain while participants relax in the scanner without a task to perform. This approach has revealed several distinct sets of brain regions that exhibit correlated patterns of activity both at rest and during cognitive tasks.

The first network to be described was the so-called “default mode” or “default network,” a set of midline and posterior inferior parietal brain regions that activate in the absence of external stimulation (Raichle et al., 2001). The default network was discovered incidentally in the late 1990s when neuroscientists began to pay more attention to what happens in the brain when participants are not engaged in a task. In most

neuroimaging experiments, brain activity is recorded during some task (e.g., solving math problems) and contrasted with some baseline condition; then, the activity specific to the task of interest is identified by subtracting the baseline activity from the data. Early neuroimaging studies tended to rely on a passive “resting state” as a baseline condition, where participants simply rested in the scanner without a task to perform. Initially, this resting period was of little empirical interest. But researchers began to notice a consistent pattern of brain activity that emerged across several experiments, raising questions about whether this pattern reflected some “default mode” of the brain.

Since the initial discovery of the default network, it has become increasingly clear that this network contributes to core functions of the mind (Buckner, Andrews-Hanna, & Schacter, 2008). The acknowledgment that the default network reflects an active mental state prompted a surge of research on its role in attention and cognition. Default activity has since been linked to spontaneous or self-generated cognition—the thoughts that arise in mind when people are not mentally engaged with the environment (Smallwood, 2013). Seminal research on mind-wandering and daydreaming provided a framework for conceptualizing neuroimaging research on the cognitive underpinnings of the default network. For example, self-reported mind-wandering was found to predict increased metabolic activity within the posterior cingulate during resting-state fMRI (Mason et al., 2007). Another key indication that the default network is involved in spontaneous thought came from task-based fMRI. Several studies reported decreased activity of the default network during cognitive and perceptual task performance (for review, see Buckner et al., 2008). During working memory tasks, for example, the default network tended to show decreased activity while executive control regions increased activation (e.g., McKiernan, Kaufman, Kucera-Thompson, & Binder, 2003). Researchers thus hypothesized that such “task-induced deactivation” reflects the suppression of task-unrelated thoughts during cognitive control. In other words, spontaneous and self-generated thoughts tend to decrease when the brain is engaged in a cognitively demanding task.

Yet the notion that self-generated thought is unrelated to task performance has recently been challenged (Andrews-Hanna, Smallwood, & Spreng, 2014). A growing literature now indicates that the default network and self-generated thought may support cognitive processes that require people to draw upon stored episodic or semantic knowledge. For example, the default network shows reliable activation when people recall past experiences or imagine future experiences (for review, see Schacter et al., 2012). Andrews-Hanna, Reidler, Sepulcre, Poulin, and Buckner (2010) have also identified subsystems within the default network that underlie various self-generated thought processes. For

example, the medial temporal subsystem, which is composed of the ventromedial prefrontal cortex, hippocampal formation, parahippocampal cortex, retrosplenial cortex, and posterior inferior parietal lobule, is preferentially involved in processes related to episodic memory, whereas the dorsal medial prefrontal cortex subsystem, which is composed of the dorsal medial prefrontal cortex, lateral temporal cortex, temporoparietal junction, and temporal pole, is preferentially involved in social cognition (e.g., mentalizing). Together, this work not only provides clear evidence that the default network is central to self-generated thought but also points to dissociable patterns of default activity that support specific cognitive processes.

The default network was originally characterized in terms of its relation to other brain networks, such as its negative correlation with the dorsal attention network during resting-state fMRI (Fox et al., 2005). However, several studies have reported cooperation of the default network and cognitive control networks during goal-directed processing. For example, the default and control networks show reliable coupling during autobiographical future planning—constructing a detailed and sequential mental representation about a future goal state (Spreng & Schacter, 2012; Spreng, Sepulcre, Turner, Stevens, & Schacter, 2013; Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010). In this context, the default network may provide self-generated information via episodic retrieval while the control network directs and monitors the integration of this information within the confines of the goal state. In the subsequent text, we provide evidence that creative cognition similarly involves such goal-directed, self-generated thought.

## BRAIN NETWORKS UNDERLYING CREATIVE COGNITION AND ARTISTIC PERFORMANCE

Researchers have used a range of tasks to probe the neural basis of both domain-general and domain-specific creative performance, including insight problem solving, divergent thinking, visual art production, musical improvisation, and many more (Arden, Chavez, Grazioplene, & Jung, 2010; Gonen-Yaacovi et al., 2013). Despite this active body of work, the field was initially marked by largely contradictory and inconsistent findings. This lack of clarity leads many to question whether creativity is too complex to distill down to a given region of the brain (Dietrich & Kanso, 2010). Another contention in the literature concerned whether creative thought involves more or less cognitive control. On the one hand, several studies reported activation of brain regions tied to executive processes, suggesting that creative thought may benefit from the focused attention and cognitive control. On the other hand, a substantial number of studies

reported activation of default network regions, pointing to the involvement of spontaneous, self-generated cognition (Wu et al., 2015).

Recently, a series of neuroimaging studies sought to address these controversies by employing new methods in brain network science (for review, see Beauty, Benedek, Silvia, & Schacter, 2016b). Network approaches can overcome limitations of conventional fMRI analysis by examining the interaction of multiple brain regions. One such study explored the role of the default and control networks during performance on a divergent thinking task (Beauty, Benedek, Kaufman, & Silvia, 2015). The task paradigm presented a series of common objects, and participants were asked to either generate alternate uses or simply think of the objects' characteristics (cf. Fink et al., 2009). Whole-brain functional connectivity analysis revealed a distributed network of brain regions associated with divergent thinking, including several regions of the default and control networks. Follow-up analyses showed direct functional connections between these network hubs during the task. Moreover, a dynamic connectivity analysis examined network patterns over time and found that default-control network coupling tended to occur at later stages of the task. The notion that creative cognition involves increased cooperation of the default and control networks receives further support from other recent work showing default-control connectivity during performance on other creative thinking tasks (e.g., Green, Cohen, Raab, Yedibalian, & Gray, 2015). Such findings suggest that creative thought involves cooperation among networks involved in self-generated thought and cognitive control.

Further evidence for the cooperative role of default and control networks comes from research on musical improvisation. Like divergent thinking research, early improvisation studies provided mixed evidence on the role of the control and default networks. A recent review of the improvisation literature reported activation across several brain regions, many within the default and control networks (Beauty, 2015). In a seminal study of piano improvisation, Limb and Braun (2008) reported widespread deactivation of control network regions (e.g., dorsolateral prefrontal cortex) and increased activation of default network regions (e.g., medial prefrontal cortex) in professional pianists during musical improvisation. This pattern was further reported in a study of freestyle rap artists (Liu et al., 2012), pointing to the involvement of spontaneous, self-generated processes in both instrumental and lyrical improvisation.

Because improvisation happens "on the spot" with seemingly little time for planning, one might expect the default network to benefit spontaneous generation at the cost of decreased cognitive control, thus reflected in the deactivation of control network regions during improvisation. On the other hand, improvisation has also been characterized as a complex and cognitively demanding task, requiring the real-time generation, evaluation, and selection of musical sequences (Beauty, 2015; Pressing, 1988).

The notion that improvisation involves cognitive control has received support from neuroimaging research showing increased activation of lateral prefrontal and premotor cortices (de Manzano and Ullén, 2012), brain regions involved in cognitive and motor control. The involvement of executive control regions leads some researchers to hypothesize that improvisation may require top-down performance monitoring via idea selection and goal maintenance (Pinho, de Manzano, Fransson, Eriksson, & Ullén, 2014). Nevertheless, such findings were seemingly at odds with research showing decreased activation of cognitive control regions in previous studies of musical improvisation.

Recently, Pinho and colleagues sought to address this paradox by examining brain network interactions during musical improvisation (Pinho, Ullén, Castelo-Branco, Fransson, & de Manzano, 2016). Professional pianists were asked to either express a specific emotion (e.g., joy) or use a specific set of piano keys (“pitch sets”) as they improvised on a keyboard during fMRI. The emotion condition was hypothesized to induce greater default network activity while the “pitch sets” condition was expected to induce greater control network activity. Univariate analysis confirmed these predictions. Critically, a functional connectivity analysis revealed increased coupling of default and control network regions during the emotion condition, suggesting that expressing a specific emotion engages both the strategic functions of the control network and the self-referential functions of the default network. In a similar vein, Ellamil, Dobson, Beeman, and Christoff (2012) examined brain activity during idea generation and evaluation in a sample of visual arts students. They found that whereas idea generation was associated with default activity, idea evaluation was associated with control network activity. Moreover, functional connectivity analysis revealed increased coupling of the default network with the control network, but only during the idea evaluation condition.

These findings provide support for the notion that creative cognition can involve goal-directed, self-generated thought. They also provide much needed nuance to the creativity literature by revealing conditions where the default and control networks are more or less engaged. For example, when artists are asked to spontaneously improvise without task constraints, they tend to exhibit increased default activity and decreased control activity (Liu et al., 2015), suggesting that artists rely more on spontaneous and self-generated cognition in the absence of explicit task goals. On the other hand, when artists are asked to tailor their ideas to meet some goal (e.g., expressing a specific emotion), they tend to show increased cooperation of the default network with executive control regions (Pinho et al., 2016). Taken together, the involvement of the control network appears to be a function of whether creative cognition is constrained to meet task-specific goals.

Another approach to understanding the role of the default network and self-generated thought in creativity is to study the creative personality. The creative person is typified by the personality trait Openness to Experience, one of the so-called “Big Five” factors of personality associated with a tendency to engage in imaginative, creative, and abstract cognitive processes (McCrae & Costa, 1997). A recent study explored whether individual differences in default network functioning could be explained by variation in Openness to Experience (Beatty et al., 2016a). Because both Openness and the default network are tied to imagination and creativity, it was hypothesized that Openness would be related to default network “global efficiency”—a network science metric used to assess information integration within complex systems. Using graph theoretical analysis of resting-state fMRI data, two studies explored whether Openness was related to efficient information flow across a functional network made up of default network nodes and corresponding edges. Across both studies, Openness significantly predicted increased default network efficiency. Thus, as Openness increased, the default network showed more efficient information flow. In this context, the ability to efficiently engage the neurocognitive resources of the default network may account for the ability of highly Open people to generate creative ideas.

### **DEFAULT NETWORK AND CREATIVE COGNITION: LINKS TO EPISODIC MEMORY**

We noted earlier that the default network has been linked to remembering past experiences and imagining future experiences (for review, see Schacter et al., 2012). More specifically, a set of brain regions referred to as the *core network* (Schacter, Addis, & Buckner, 2007), which largely overlaps with the default network, shows similarly increased activity when people remember past experiences or imagine future experiences (for a recent meta-analysis, see Benoit & Schacter, 2015). According to the constructive episodic simulation hypothesis (Schacter & Addis, 2007), these neural similarities, and corresponding cognitive similarities between remembering the past and imagining the future (Schacter et al., 2012; Szpunar, 2010), reflect to a large extent the influence of episodic memory on imagining future and other hypothetical experiences. Episodic memory, as classically defined by Tulving (1983, 2002), entails remembering specific experiences from one’s personal past, but it now seems clear that episodic memory plays a broader role in cognition (Moscovitch, Cabeza, Nadel, & Winocur, 2016). Schacter and Addis (2007) have argued that episodic memory includes flexible retrieval processes that allow people to recombine elements of past events in order to generate simulations of novel future events that they have not yet experienced. This ability to simulate a

variety of possible future events without having to engage in the actual behaviors that are represented in simulations is thought to be a highly adaptive cognitive ability (cf., Gilbert, 2006; Ingvar, 1979; Schacter, 2012; Schacter & Addis, 2007; Suddendorf & Corballis, 2007).

Episodic simulation of possible future experiences thus resembles in some respects divergent creative thinking, which involves generating creative ideas by combining diverse kinds of information in novel ways (Guilford, 1967). In light of this similarity, and the association of both divergent thinking and episodic simulation and memory with the default network, there is reason to suspect that episodic memory might contribute to divergent creative thinking. The results of several recent studies provide experimental support for this hypothesis.

Two lines of evidence support this idea, at least indirectly, by linking divergent thinking with the hippocampus, a structure that has long been thought to play an important role in episodic memory. Duff, Kurczek, Rubin, Cohen, and Tranel (2013) found that amnesic patients with severe impairments of episodic memory as a consequence of bilateral hippocampal damage are also impaired on the Torrance Tests of Creative Thinking, which provide a broad assessment of divergent thinking. Evidence from recent fMRI studies points in the same direction. As noted earlier, Ellamil et al. (2012) found that brain regions frequently associated with episodic memory, including the hippocampus, show increased activity when participants generate creative ideas while designing book cover illustrations. Benedek et al. (2014) reported that the hippocampus was among the regions that showed increased activation when participants performed a standard test of divergent thinking—the Alternate Uses Task (AUT), which requires generating alternative uses for common objects. Although consistent with a contribution of episodic memory to divergent thinking, these findings are not conclusive because (1) hippocampal amnesic patients typically exhibit deficits in forming new semantic memories, as well as new episodic memories (e.g., Eichenbaum & Cohen, 2001; Squire, Stark, & Clark, 2004), so it is difficult to determine conclusively whether the divergent thinking deficits in such patients, as reported by Duff et al. (2013), specifically implicate episodic memory; and (2) although activation in the hippocampus during creative idea generation and divergent thinking (Benedek et al., 2014; Ellamil et al., 2012) is broadly consistent with a role for episodic memory, such correlational observations do not provide conclusive evidence that episodic memory supports divergent thinking.

Behavioral evidence, however, points in the same direction. Healthy young adults occasionally draw on episodic memories when performing the AUT, primarily during the early phases of task performance (Gilhooly, Fioratou, Anthony, & Wynn, 2007). In a study of healthy young and older adults, Addis, Pan, Musicaro, and Schacter (2016) reported that performance on the AUT is positively correlated with the number of episodic

details that participants report when they imagine possible future experiences. However, this correlation with AUT performance was specific to imagined future events, and was not observed for imagined or recalled past events.

Madore, Addis, and Schacter (2015) provided a stronger link between episodic memory and AUT performance in experiments in which participants received an *episodic specificity induction*—brief training in recollecting specific details of a recent experience—prior to performing the AUT. The specificity induction used in this study is based on the well-established Cognitive Interview (CI; Fisher & Geiselman, 1992), a protocol used primarily in forensic contexts to increase episodic retrieval from eyewitnesses. When receiving the CI-based specificity induction, participants are encouraged to focus on episodic details pertaining to people, objects, and actions in a recently viewed video of an everyday scene (i.e., people performing actions in a kitchen setting). Several previous studies have shown that this specificity induction, compared with a control induction where participants provide their general impressions of a recently viewed video, selectively boosts the number of episodic details that participants provide on subsequent tasks that require remembering past experiences and imagining future experiences, while having no effect on the number of semantic details that participants provide on such tasks (Jing, Madore, & Schacter, 2016; Madore, Gaesser, & Schacter, 2014; Madore & Schacter, 2016; for review, see Schacter & Madore, *in press*).

In the study by Madore et al. (2015), specificity and control inductions were given prior to performance on two key tasks: the AUT and an object association task that required participants to generate common associates of objects but did not require divergent thinking. Critically, the specificity induction resulted in a significant increase in the number of appropriate uses that participants generated on the AUT, while having no effect on performance of the object association task. A second experiment compared effects of the specificity induction on AUT performance with performance of a task that taps convergent thinking, that is, the ability to generate the best single solution to a problem. To assess convergent thinking, Madore et al. (2015) used a remote associates test (RAT; Bowden & Jung-Beeman, 1998; Mednick, 1962), which requires participants to generate a solution word that forms a common word/phrase with each of the three main parts of a target word triad (e.g., for “Eight/Skate/Stick” the solution word is “Figure”). Results revealed that once again, the specificity induction significantly boosted performance on the AUT, but failed to produce a significant effect on the RAT.

Taken together, these findings suggest that episodic memory does make a contribution to creative cognition, but the contribution may be limited to divergent thinking. Schacter and Madore (*in press*) have argued that the specificity induction biases the way in which participants approach

cognitive tasks by encouraging them to focus on episodic details related to places, people, objects, or actions, which in turn impacts subsequent performance on those tasks that involve, at least to some extent, creating mental events or scenes that contain details like those emphasized during the specificity induction. By this view, a divergent thinking task, such as the AUT involves the creation of mental events or scenes as participants attempt to imagine novel ways in which a familiar object could be used, and the specificity induction may help participants to create or retrieve more detailed mental events that support the generation of novel uses. Although much remains to be learned about the relations among episodic memory, episodic simulation, and divergent thinking, and the extent to which they depend on the same or different regions within the default network, it seems clear that future research in the area of creative cognition should explore these relations more fully.

## CONCLUSIONS AND FUTURE DIRECTIONS

The research described earlier highlights the contribution of self-generated thought and the default network to creativity. We propose that the cognitive processes associated with this network—namely, self-generated thought and episodic memory—play a central role in the production of creative ideas. This notion has received support from behavioral research showing consistent involvement of episodic memory in creative cognition, suggesting that the ability to draw upon and flexibly recombine memory representations reflects a core mechanism underlying creative thought. Recent work also implicates cognitive control processes in creativity, particularly when idea production must be constrained to meet specific creative goals (Beaty et al., 2016b). Taken together, we conclude that creative thought can benefit from both goal-directed and self-generated thought.

An important direction for future neuroimaging research is to determine which aspects of self-generated thought are relevant for creative cognition. As noted earlier, self-generated thought can involve spontaneous cognition (e.g., mind-wandering; Smallwood, 2013), but the extent to which creativity actually benefits from such spontaneous processes remains unclear. Notably, recent behavioral research suggests that mind-wandering may hinder creative idea production (Hao, Wu, Runco, & Pina, 2015). In this context, the default network's involvement in creativity might not reflect spontaneous thought per se, but rather the operation of some other process, such as episodic memory (Schacter et al., 2012). Future neuroimaging research could employ experimental paradigms designed to disentangle the complex relationship between creativity and the default network. For example, the episodic specificity induction described earlier (Madore et al., 2015) could be employed in fMRI experiments to

determine whether episodic memory accounts for patterns of default activity during creative cognition.

Future research should also further delineate the contribution of cognitive control in creative thought. Based on the evidence described earlier, we propose that creativity may benefit from control processing in contexts where idea generation is constrained to meet task-specific goals (Beaty et al., 2016b). For example, Pinho et al. (2016) reported increased cooperation of control and default network regions when pianists improvised melodies based on a predefined emotion. Thus, cognitive control may be beneficial when people attempt to tailor their ideas to fit the demands of a predefined creative problem. Nevertheless, although both cognitive control and self-generated thought appear to be important for creativity, understanding how these networks interact to support complex creative behaviors remains an open and interesting question for future research.

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