

Journal Club

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A Domain-General Role for the Angular Gyrus in Retrieving Internal Representations of the External World

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Review of Bonnici et al.

Introduction

Autobiographical memories for personal past experiences vary along multiple interrelated dimensions, such as sensory-perceptual, spatiotemporal, and emotional information (Rubin, 2005). The complex, highly relational nature of information within autobiographical memory allows us not only to relive personal past experiences, but further confers a sense of subjective time, and shapes a sense of self. Understanding how the human brain stores and accesses the rich content of our autobiographical memories has, therefore, been a longstanding goal of memory research.

The retrieval of autobiographical memories involves activity distributed among multiple regions of a “core memory network,” including prefrontal, medial temporal, and medial and lateral parietal cortices (Svoboda et al., 2006). Recently, there has been increasing interest in the contributions of the lateral parietal cortex, specifically the left angular gyrus (AG), to autobiographical and episodic memory retrieval. This interest

has been stimulated by findings reliably demonstrating activity in the left AG during memory retrieval in studies using fMRI or electroencephalography (Wagner et al., 2005). Specifically, retrieval-related activity in the left AG scales parametrically with the strength and recollection of fine-grained details from memory (for review, see Rugg and King, 2018) to the extent that stimulus category can be successfully decoded from recall-related activity in the left AG (Kuhl and Chun, 2014). Overall, these findings suggest an important role for this region in memory.

Although implicated in memory retrieval, direct evidence for the necessity of the AG to episodic and autobiographical remembering is limited. Classical descriptions of patients with lateral parietal lesions (centered on the AG) report the onset of dyscalculia and dysgraphia (Gerstmann, 1940), but do not mention frank amnesia. More recent and systematic characterizations of patients with lateral parietal lesions (encompassing the AG) report qualitative changes in both autobiographical (Berryhill et al., 2007) and episodic memory (Ben-Zvi et al., 2015). Specifying the exact nature of memory deficits across these studies has, however, remained difficult because of variability in lesion location and size, functional reorganization occurring after the lesion, and challenges in dissociating encoding- ver-

sus retrieval-related impairments (Rugg and King, 2018). Therefore, the question of whether the AG is truly necessary for memory retrieval has remained unanswered.

To determine the necessity of the left AG in autobiographical memory retrieval, Bonnici et al. (2018) used continuous theta burst stimulation (cTBS) to temporarily inhibit AG function while healthy adult participants recalled and elaborated on their autobiographical memories. In an initial “memory gathering” phase, participants selected and named five personally significant memories from distinct life epochs (childhood, adolescence, early adulthood, and the previous year). The selected memories were given names, which served as participant-specific cues triggering rich and vivid recall of the autobiographical events. The memory gathering phase was followed by an episodic learning phase in which subjects created sentences from word pairs presented visually and aurally. This condition was imperative to test whether AG disruption elicited selective deficits in autobiographical recall or whether it extended to broader forms of episodic recall. Subsequently, cTBS was administered to the left AG, in the experimental condition, or to the vertex as a control site. Participants then engaged in free and cued recall of selected autobiographical memories, and the quality of memory recall was assessed using a stan-

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standardized protocol (for an autobiographical interview, see Levine et al., 2002). Participants were also asked to indicate whether recollected autobiographical memories were experienced from a first- or third-person perspective, as the AG has been proposed to be involved in egocentric processing within autobiographical retrieval (St Jacques et al., 2011). Finally, participants performed free and cued recall of studied word pairs. To counterbalance the stimulation site (left AG vs vertex), participants returned a week later and underwent a second session involving free and cued recall of a new set of autobiographical memories and word pairs following the same procedures.

Bonnici et al. (2018) found that inhibitory cTBS to the left AG selectively disrupted free recall of autobiographical memories. In particular, stimulation of the left AG caused participants to recall fewer details pertaining to their selected autobiographical events. Furthermore, participants tended to report fewer autobiographical memories from a first-person perspective after AG stimulation, implicating the AG in the subjective experience of autobiographical recall. In contrast, AG stimulation had no effects on cued recall of autobiographical memories, or on free or cued recall of word pairs. In summary, these findings suggest a role for the AG in the subjective experience of remembering, and provide evidence implicating the AG in the retrieval of rich, autobiographical content.

The AG processes internal representations of the external world

While Bonnici et al. (2018) interpret the AG's role as supporting the subjective experience of remembering, we extend this suggestion to posit that the AG is involved in retrieving and subsequently representing any internally generated information that is inherently rich in context and highly relational. By this view, the impoverished subjective quality of remembering after inhibitory stimulation of the AG reflects a downstream consequence of impaired retrieval of relational sensory-perceptual contextual details, which are essential for a vivid subjective experience of remembering (Ramanan et al., 2018a). Furthermore, AG stimulation may not impair word pair recall simply due to its relative lack of rich, highly relational content, otherwise typical of autobiographical memories. Importantly, adopting this broader perspective more easily accounts for a role of the AG outside of memory research and moves us a step closer to-

ward specifying its potential function across multiple cognitive domains.

The AG is a higher-order association cortex, located at the nexus of multiple brain networks and sensory-association cortices (Seghier, 2013). One distinguishing feature of the AG is its neuroanatomical segregation from early sensory-processing regions (Margulies et al., 2016). Activity in the sensory cortices is yoked to changes in the external world, providing high-fidelity representations of our immediate external environment. Regions that are neuroanatomically segregated from sensory inputs, such as the AG, however, operate independently from fluctuations in the immediate environment, a feature thought to be defining of regions that process internally generated thought (Mesulam, 1998). Activity in the AG is also characterized by extended history dependence, in that information encoded from many minutes ago continues to influence ongoing activity (Hasson et al., 2015). These convergent findings suggest that AG activity may support internal models of the external environment. Notably, autobiographical memory is centered on interactions between sensory-perceptual details of past events and associated self-related representations. AG activity during autobiographical recall can, therefore, be conceptualized as the reconstruction of an internal representation of rich, highly relational autobiographical content (Ramanan et al., 2018a). Accordingly, qualitative changes in subjective remembering after AG damage likely reflect primary disruption of the core features of the reconstructed internal model of the autobiographical event, rather than an independent reduction in the vividness of the memory.

Unlike autobiographical content, our memory for arbitrary word pair associations is markedly less rich and complex in features. Encoded word pairs generally lack personal significance and arise in highly homogeneous contexts, such as a controlled laboratory environment, where a pool of word pairs are learned together. If the AG is proposed to be involved in the retrieval of rich, highly relational, internally generated content, one may not expect disruption of AG activity to impair word pair recall (as found by Bonnici et al., 2018). This is not to say the AG is not involved in the recall of laboratory-based stimuli, but rather, AG involvement in memory retrieval may be modulated by the degree to which the retrieved content is detail-rich and highly relational, as would be expected when retrieval is characterized by strong and vivid

recollection of the encoding experience (Rugg and King, 2018).

Beyond autobiographical memory, the AG is particularly sensitive to processing social context (Carter and Huetzel, 2013), semantic concepts (Price et al., 2015), narrative content (Hasson et al., 2015), and scenarios involving vivid future thinking and atemporal imagination (Thakral et al., 2017; Ramanan et al., 2018b). Importantly, all of the aforementioned cognitive functions rely on internally generated thought, largely independent of the immediate external environment. For successful task performance using any of the above cognitive functions, it is essential that one rely on the retrieval and subsequent application of relevant internal models of social information, world knowledge, or past experience.

In conclusion, the findings of Bonnici et al. (2018) advance our understanding of AG contributions to representing rich, complex information characteristic of autobiographical retrieval. It is important for future studies to move toward probing the cognitive mechanisms underpinning AG involvement in processing real-world representations. In line with our proposal, adopting a domain-general role for the AG in the representation of internally generated information, grounded strongly in its neuroanatomical profile, may provide a useful anchor for future research attempting to decipher the functions of this region.

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