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Dissecting the neuroanatomy of creativity and curiosity: The subdivisions within networks matter

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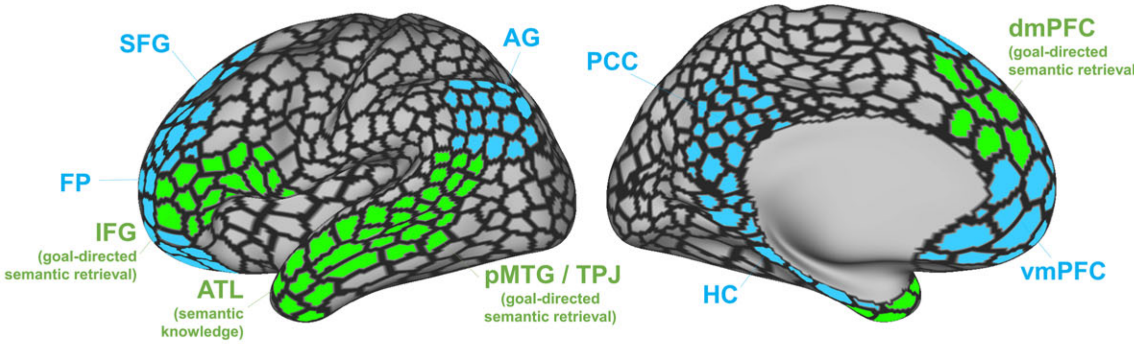
Abstract

Ivancovsky et al. (2023) argue that the neurocognitive mechanisms of creativity and curiosity both rely on the interplay among brain networks. Research to date demonstrates that such inter-network dynamics are further complicated by functional fractionation within networks. Investigating how networks subdivide and reconfigure in service of a task offers insights about the precise anatomy that underpins creative and curious behaviour.

Researchers generally agree that creative ideation needs to fulfil two criteria (Sternberg & Kaufman, 2010) – originality and effectiveness. *Originality* pertains to combining pre-existing concepts in novel and unique ways, while *effectiveness* relates to whether the new combination of old ideas can satisfactorily solve a problem or appropriately fit into a context by considering relevant constraints. These definitions naturally map onto distinct stages of cognitive processing (Benedek, Beaty, Schacter, & Kenett, 2023) – idea generation (forging novel links between concepts) and idea evaluation (assessing whether the new idea is goal-relevant or sufficiently innovative). Neuroimaging evidence has demonstrated that the two stages rely on distinct dynamics amongst several brain networks – for example, the default, salience, and executive control networks (Beaty, Benedek, Silvia, & Schacter, 2016). The theory paper by Ivancovsky et al. (2023) comprehensively reviewed the neuroimaging literatures of creativity and curiosity, identified multiple similarities in the neurocognitive mechanisms of the two, and proposed a novelty-seeking model to account for the commonalities between creative pursuits and curiosity-driven behaviour.

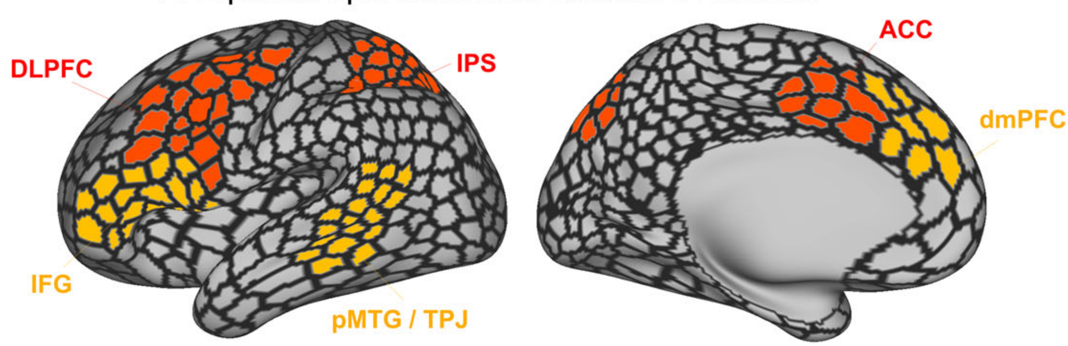
We agree with Ivancovsky et al.'s proposal that both creativity and curiosity are multidimensional constructs that entail multiple stages of cognitive processing and depend on the interaction between multiple brain networks. One important caveat, however, should be considered – decades of connectomic research have demonstrated that the default network and executive network are both highly heterogeneous systems, consisting of multiple subnetworks that differ with respect to their functional tunings and connectomic fingerprints. For example, research from our laboratories and other research teams have shown that the default network is functionally fractionated into (at least) two subnetworks – one is more associated with semantic memories, evaluative cognition and convergent thinking, while the other is more associated with episodic memories, free association, simulating hypothetical scenarios and divergent thinking (e.g., Chiou, Humphreys, & Lambon Ralph, 2020, 2023a; Krieger-Redwood et al., 2023; Zhang et al., 2022). As illustrated in Figure 1(A), the "semantically oriented" subnetwork consists of the inferior frontal gyrus, anterior temporal lobe, temporoparietal junction and dorsomedial prefrontal cortex, while the "episodically oriented" subnetwork consists of the ventromedial prefrontal cortex, posterior-cingulate/retrosplenial cortex, hippocampi and angular gyri. This "semantic *versus* episodic" dissociation topographically accords with conventional taxonomy of subregions within the default network (e.g., Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010) – the semantic subnetwork overlaps substantively with the dorsomedial subsystem, while the episodic subnetwork overlaps significantly with the medial-temporal and core subsystems. Such dissociation was not only observed in the subnetworks' tuning for task contexts but also in intrinsic connectivity under task-free situations (e.g., Yeo et al., 2011). Like the default network, the brain's executive control network can also be functionally split into (at least) two subnetworks. One is associated with exerting cognitive control over memory-based representations, including both

(A) Bipartite split within the default network



subnetwork	constituent regions	preferred memory	preferred tasks	potential role in creativity
semantic network	bilateral anterior temporal lobes (ATL) left inferior frontal gyrus (IFG) left post. mid-temporal gyrus (pTMG) left temporoparietal junction (TPJ) dorsomedial prefrontal cortex (dmPFC)	semantic memory	convergent thinking analytical thinking evaluative cognition semantic decision problem solving	ATL may provide the semantic contents for idea generation IFG, pMTG, TPJ, dmPFC may be involved in idea evaluation
episodic network	bilateral angular gyri (AG) bilateral hippocampi (HC) post.-cingulate/retrosplenial cortex (PCC/RSC) ventromedial prefrontal cortex (vmPFC) frontal pole (FP) & superior frontal gyrus (SFG)	episodic memory	episodic retrieval social cognition theory of mind mental simulation free association	All these areas may be involved in retrieving past episodes or simulating imagined scenarios to support creativity

(B) Bipartite split within the executive network



subnetwork	constituent regions	preferred tasks	potential role in creativity
Memory control (a.k.a. semantic-control network)	left inferior frontal gyrus (IFG) left post. mid-temporal gyrus (pMTG) left temporoparietal junction (TPJ) dorsomedial prefrontal cortex (dmPFC)	All these areas are involved in goal-directed retrieval of semantic memory; in addition, the IFG is involved in episodic retrieval	This network may be involved in idea evaluation, comparing the suitability or efficacy of ideas
Perception control (a.k.a. multiple-demand network)	dorsolateral prefrontal cortex (DLPFC) bilateral intraparietal sulci (IPS) middle/anterior cingulate cortex (ACC)	All these areas are involved in goal-directed operation on perceptual representations (e.g., visual search or visual/auditory n-back)	This network may be involved in directing attention to relevant perceptual input during creation

Fig. 1 - Colour online

Figure 1 (A) The bipartite split within the brain's default network. (B) The bipartite split within the brain's executive network. Note that the network affiliations of the IFG, left pMTG/TPJ and dmPFC are fluid – while these regions are classified as nodes of the default network during the resting-state, they can also be involved in controlled retrieval of semantic/episodic memory in task situations.

semantic memories and episodic memories (e.g., Chiou, Jefferies, Duncan, Humphreys, & Lambon Ralph, 2023b; Gao et al., 2021; Vatansever, Smallwood, & Jefferies, 2021), while the other is associated with exerting control over perception-based representations (e.g., Assem, Glasser, Van Essen, & Duncan, 2020, 2022; Branzi & Lambon Ralph, 2023). As shown in Figure 1(B), the subnetwork biased towards the control of memory includes the inferior frontal gyrus and the posterior mid-temporal gyrus, while the subnetwork biased towards controlling perception includes a large swath of the dorsolateral prefrontal cortex, middle/anterior cingulate cortex and intraparietal sulcus. Furthermore, connectivity evidence shows that regions biased for mnemonic/semantic control tightly couple with the default network, while regions biased for perceptual control closely link with the visual cortex and dorsal-attention network (Dixon et al., 2018).

Given this functional heterogeneity, we suggest that Ivancovsky et al.'s proposal that "*creativity relies on the interaction amongst brain networks*" and "the *generation and evaluation of creative ideation relies respectively on the default and executive network*" is under-specified. Further research is needed to pinpoint how the division of default and executive systems into subnetworks enables distinct facets of creativity. Recently, we have begun to unravel how different types of creative ideas are underpinned by distinct component regions of these networks. Using a multivariate regression approach with functional MRI, we showed that when creativity is built on semantic memory, it is associated with greater activity in regions involved in semantic retrieval (the inferior frontal gyrus and dorsomedial prefrontal cortex) while minimally engaged those regions for episodic memory; on the other hand, when creativity is built on episodic memory, it is associated with greater activity in regions involved in episodic memory (the retrosplenial cortex) while minimally recruited those regions for semantic memory (for details see Krieger-Redwood et al., 2023). Particularly, when participants attempted to produce creative links between word-pairs that are barely semantically related (e.g., marigold and sphinx), the brain reacted to such a semantically challenging situation with extensively distributed activation spread across the semantic subnetwork (inferior frontal gyrus) and executive network (dorsolateral prefrontal cortex and anterior cingulate cortex), potentially reflecting the mental manoeuvre between paying attention to text and recombining semantic concepts. Interestingly, such widespread, cross-network activation disappeared when participants produced creative links between closely related words (e.g., flight and holiday); instead, this situation elicited activation of the retrosplenial cortex, which dovetailed with participants' report that they inclined to episodic retrieval in this context (e.g., recalling a recent trip).

Taken together, multiple evidence consistently indicates that both semantic and episodic memory contribute to the emergence of creative ideas (Benedek et al., 2023). Under different circumstances, the brain employs distinct cognitive tactics and neural machineries to engender creative ideas, depending on whether semantic concepts are assembled in a novel way or episodic memories are used to create quirky contents.

While the novelty-seeking model proposed by Ivancovsky et al. (2023) nicely integrates two forms of introspective processes, creativity and curiosity, with various cognitive processes and brain networks, it remains to be clarified how their model fits with evidence for the fractionation of networks into subparts and their flexible network-wide reconfiguration to suit different contextual requirements. Although fractionations and reconfigurations complicate current theories about the neural substrates of creativity, these considerations provide a more truthful description of the underlying mechanisms. A fruitful direction for future research is to consider the fusion and fissure within and between networks, which can provide valuable insights regarding how the brain implements flexible cognition.

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