On semantic structures and processes in creative thinking

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Kounios and Oh [1] offer a perspective on our recent review on the role of associative processes in creativity [2], highlighting potential theoretical considerations surrounding semantic memory structure. Kounios and Oh critique network-based approaches to representing semantic memory that rely, in their view, on behavioral tasks "downstream" from the original source of semantic representation. Instead, they advocate for "upstream" processes of semantic activation via electrophysiological methods (the N400 component).

Our review does not focus on semantic memory structure, but rather on the processes operating over it—namely associative processes—and how such processes relate to individual differences in creativity. Rapid developments in computational methods have made considerable advancements in representing semantic memory *structure* (i.e., how we organize concepts in memory) and studying associative *processes* (i.e., how we search through concepts in memory) via network science and natural language processing [for a recent and comprehensive review, see 3]. Such developments provide useful metaphors to describe semantic memory [4]—such as a vehicle searching (i.e., *process*) over a semantic space (i.e., *structure*)—and propelled our understanding of how semantic memory supports the creative thought process [5,6].

These computational advancements allow us to empirically study associative processes, which have long been viewed as key to the creative thought process. Although associative thinking has been intuitively embedded in creativity theories for decades, it is still debated whether individual differences in creativity relate to semantic memory structure or the associative processes that operate over it [7]. This debate is indeed echoed in Kounios and Oh [1]. Yet, the message we aimed to convey in our review goes beyond this theoretical debate, by arguing, "Higher creative individuals are better able to *navigate* semantic memory: they travel further when associating, switch between more semantic subcategories, and make larger leaps between associations" [2; p. 680]. Hence, our review focuses more on the process, and less on the structure.

We advocate for the continued application of computational methods to study the complexity of cognitive capacities that bring forth human creativity. Network science is one such approach, offering a formal mathematical way to represent complex systems as graphs, or networks and the processes that operate over them. Network science has gained significant popularity across all fields of science, including cognitive science [8], with an emphasis on semantic memory [3].

Further, the rapid development of large language models (e.g., GPT-4) offer unprecedented opportunities to model human cognition, and have already begun to reshape how creativity is empirically studied [9]. Such developments are allowing us to uniquely examine the role of associative thinking as a general mechanism in the creative thought process, by quantifying the "semantic distance" between associative responses. Indeed, more creative individuals, such as artists, generate associations with higher distances, thus generating more remote, original ideas.

One example of an adjacent domain is cognitive search. A prominent metaphor in cognitive search is that humans search their mind similar to how animals search, or forage, for food by *exploiting* patches of food (clustering) and, when exhausted, *exploring* for new patches of food (switching) [10]. Computational models have been applied to study how people perform mental search via semantic fluency or free association tasks. Recently, we employed such computational approaches to study mechanisms of cognitive search in relation to individual differences in creative thinking [11]. Our results indicated that both exploration and exploitation stages of cognitive search are largely an attention-based, goal-directed process, highlighting the need for a new metaphor to conceptualize memory search processes.

Finally, Kounios and Oh [1] advocate for the ERP N400 component as a marker of semantic memory. We agree that the N400 component is an important electrophysiological marker of semantics and should be further examined in creativity research. However, the N400 component is considered to indicate semantic incongruity, or semantic integration, and not semantic storage. Furthermore, the specific cognitive function of the N400 is still debated, as its effects have also been found for non-semantic related phenomena [12].

Overall, we believe it is important to differentiate structure from process when studying semantic memory, a debate that is largely driven by the metaphors we use to describe it [4]. It is also clear that semantic memory plays an important role in creativity [5,6]. Our review highlights how recent advancements in computational methods are enabling empirical research on the *process* of generating creative ideas. Associative thinking appears to play a central role in the creative thought process, from idea generation to artistic expertise.

While much more work remains, with current computational methods we finally have the means to empirically move forward. Such scientific advancement requires updating the metaphors we use along the way, such as the map (structure) and vehicle (process) metaphor [4]. Nevertheless, we believe computational tools open the door to a deeper understanding of the creative process, including how we mentally travel through memory when thinking creatively.

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