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The Role of Knowledge in Creative Thinking

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ABSTRACT
In this invited paper, I briefly review my past, current, and future lines of research. The associative theory of creativity argues that higher creative individuals have a richer semantic memory structure that facilitates broader associative search processes, that leads to the combination of remote concepts into novel and appropriate ideas. Based on this theory, in my research I investigate the role of knowledge – or semantic memory – in high-level cognition, focusing on creativity, associative thinking, and memory search, in typical and clinical populations. To do so, I apply computational tools from network science, natural language processing, and machine learning, coupled with empirical cognitive and neural research. Such computational tools are enabling the representation and operationalization of the structure of semantic memory and the processes that operate over it. This is critical as it allows us to start quantifying issues that for a very long time were studied very subjectively in creativity research – remoteness of ideas, associative thinking, flexible/richer semantic memory structure, etc. Such work is offering unique, quantitative, ways to directly study classic theories of creativity, propelling forward our understanding of its complexity.

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Introduction

The human mind can be extremely flexible as we solve problems and create new ideas, in an increasingly complex world. How can we possibly study the complex multiple cognitive capacities that support such flexibility? More generally, how can we study the complex cognitive and neural processes and dynamics that give rise to higher-level cognition?

Creativity, as an example, involves multiple cognitive processes interacting together in complex dynamics—e.g., cognitive control, fluid intelligence, imagination, and memory (Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014) – but is far from understood. Creative ideation refers to the cognitive process of generating novel and effective ideas (Green, Beaty, Kenett, & Kaufman, 2023; Runco & Jaeger, 2012). Creative ideation is typically examined with divergent thinking (DT) tasks such as the alternative uses task (AUT) that pose open-ended problems and requires participants to come up with several creative solutions (Acar & Runco, 2019; Runco & Acar, 2012). Creative ideation – as measured with DT tasks – is the most thoroughly studied aspect of creativity, broadly viewed a critical component of creativity (Runco & Acar, 2012; Said-Metwaly, Taylor, Camarda, & Barbot, 2022).

My research centers around the role of knowledge – or, semantic memory – in high-level cognition, such as creativity (largely, creative ideation). Specifically, the role of semantic memory (memory of knowledge and facts) in creativity is theoretically acknowledged but traditionally only indirectly investigated (Abraham & Bubic, 2015). One reason for this omission is the challenge of representing the organization of semantic memory; a challenge that is compounded when modeling the cognitive processes that operate on semantic memory, such as learning or memory search processes (Hills & Kenett, 2022; Kumar, 2021).

The role of semantic memory structure in creativity has been most prominently highlighted by the associative theory of creativity (Mednick, 1962). According to this theory, individual differences in semantic memory structure influence creative thought. It proposed that higher creative individuals (scoring higher on creativity tests, such as the AUT) are characterized by “flat” associative hierarchies (numerous and weakly related associations to a given concept) rather than “steep” associative hierarchies (few and strong associations to a given concept) characterized in lower creative individuals (scoring lower on creativity tests, such as the AUT) in semantic memory (However, see Benedek & Neubauer, 2013). Creativity, the theory argues, is realized by the ability to associatively spread more broadly through such a semantic memory structure, connecting

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concepts that are remote from each-other into novel and appropriate new ideas. The more remote the original ideas are from each other, the more creative the new idea will be (Mednick, 1962). As such, I theoretically argue – and empirically study – that creativity involves search processes throughout semantic memory, constrained by its structure (Figure 1).

The goal of my work is to understand how cognitive and neural processes and dynamics support higher-level cognition, such as creative thinking. To achieve this goal, I apply a multidisciplinary approach, integrating classic insights and methods from cognitive psychology and neuroscience, with computational methods from network science, machine learning, and natural language processing. This approach can more directly characterize models of semantic memory and processes that operate over it, in typical and clinical populations. Rapid developments in computational methods and their application in creativity research are propelling our ability to study its complexity (Lloyd-Cox, Pickering, Beaty, & Bhattacharya, 2023). Critically, such computational research has significantly allowed us to study the role of memory in creativity (Benedek, Beaty, Schacter, & Kenett, 2023) and the associative processes that realizes it (Beaty & Kenett, 2023). In what follows, I will make an attempt to highlight the potential of converging computational methods with empirical research in creativity. This, by a humble attempt to review my past, current, and future research.

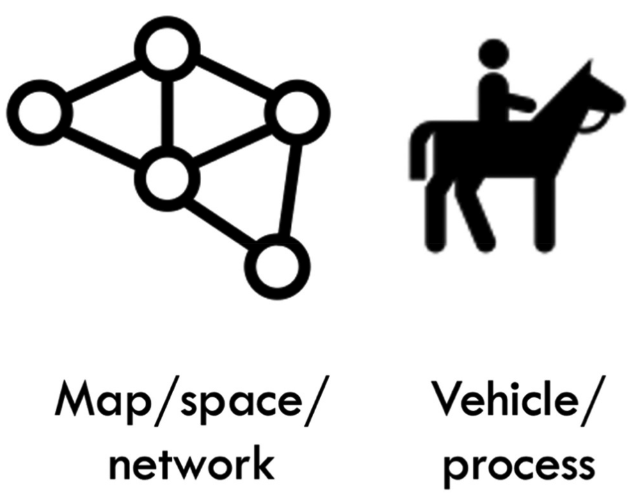

Figure 1. To study the role of semantic memory in creativity we assume that (left) knowledge is organized in some way, such as a map, space, or network, in which concepts are related to each other; and (right) search processes operate (as a vehicle) over this semantic space, resulting in memory search, retrieval, and creative combination. Adapted from Hills and Kenett (2022). The associative theory of creativity argues that higher creative individuals have a richer semantic memory structure that allows them to search more broadly in their memory (Mednick, 1962).

Given space limitation, I will mainly focus on cognitive research. However, parallel similar questions can be examined at the neural level, for example is the creative brain "wired" differently than the less creative brain, or what are the neural dynamics that support creative thinking (Beaty & Kenett, 2020).

The past: mapping

I have been investigating, from my PhD research onwards, the role of semantic memory structure in high-level cognition, focusing on creativity, associative thinking, and memory search. Harnessing computational network science methodologies – providing quantitative methods to investigate complex systems as networks (Siew, Wulff, Beckage, & Kenett, 2019) – I quantitatively examined the structure of semantic memory networks (SemNets) of lower and higher creative individuals (Kenett, Anaki, & Faust, 2014). Participants in this study were assigned as lower or higher creative, based on a battery of DT tasks. These SemNets are composed of cue words (nodes) and the relation between them is based on the group-level similarity of free associations generated to these cue words (edges). In accordance with the associative theory of creativity, I found that concepts in the SemNet of higher creative individuals are more connected and closer to each other (Kenett, Anaki, & Faust, 2014). This was the first direct and quantitative investigation of the associative theory of creativity (Figure 2).

My original research on the SemNets of lower and higher creative individuals led me down an unexpected rabbit hole, one which I am grateful for. Several further computational modeling studies of mine have demonstrated how a "flexible" SemNet structure (Kenett et al., 2018) – a structure where concepts are closer to each other and more richly connected – is conducive to higher creative ability in groups (Kenett, Anaki, & Faust, 2014; Kenett, Beaty, Silvia, Anaki, & Faust, 2016) and individuals (Benedek et al., 2017; He et al., 2021; Ovando-Tellez, Kenett et al., 2022). A more connected, less structured SemNet facilitate one's ability to generate more creative ideas, by searching over their semantic memory and connecting weakly related concepts together (Kenett & Austerweil, 2016). This work was largely summarized in a 2019 *Trends in Cognitive Sciences* paper of mine, titled "A semantic cartography of the creative mind" (Kenett & Faust, 2019). Recently (Ovando-Tellez, Kenett et al., 2022), we have also demonstrated how differences in individual-based SemNets predicted real-life creative behavior, assessed via the Inventory of Creative Activities and Achievements (Diedrich et al., 2018). Furthermore,

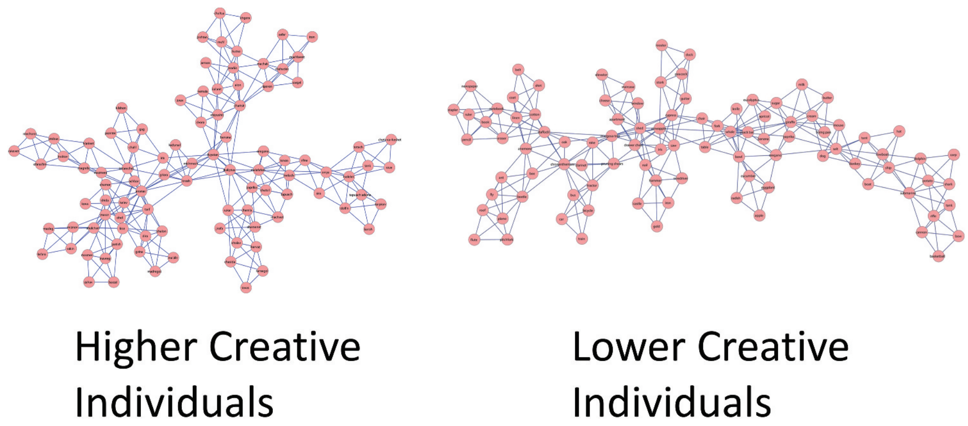

Figure 2. A 2D representation of the 96 cue word (nodes) SemNets of lower and higher creative individuals. Edges represent symmetrical similarity between nodes. Higher creative individuals have a more flexible SemNet: nodes are closer and more connected to each other, facilitating broader creative search. Adapted from Kenett, Anaki, and Faust (2014).

we have also shown how such a flexible SemNet structure has been related to individuals higher in Openness to Experience (Christensen, Kenett, Cotter, Beaty, & Silvia, 2018), more successful in solving creative convergent thinking tasks (Luchini et al., 2023), or those better in producing metaphors (Li, Kenett, Hu, & Beaty, 2021). In parallel, as I continued walking down this SemNet path, I found myself investing growing effort in contributing to the establishing the field of Cognitive Network Science (Siew, Wulff, Beckage, & Kenett, 2019), and developing tools to facilitate its application (Christensen & Kenett, 2023).

Thus, individual variation in semantic memory structure plays a critical role in creativity, as proposed by the associative theory of creativity (Mednick, 1962). Applying network science methods to map the SemNet structure of the creative mind is increasingly revealing quantitative insights on the complexity of creative thinking. In a recent study from my lab, we capitalize on such insights, developing a tool we call the associative creativity sparker. Our tool identifies where participants get "stuck" in their SemNet when generating alternative uses in the AUT, and proposes word recommendations that help them "pull out" of mental fixation. Despite our work being a proof-of-concept, it highlights the transformative aspects of such creativity SemNet research.

The present: searching

Based on the extensive research I have been conducting on variation in SemNet structure in relation to individual differences in creativity, I am presently focusing my research on the second aspect of the associative theory of creativity: Creatively searching our memory (Kenett, 2023). After all, the theory argues that a more flexible semantic memory structure facilitates broader search processes that lead to the connection of remote concepts (Mednick, 1962). But how can we empirically study such search processes? Such empirical research is made possible with current quantitative operationalization of semantic distance, via network-based or linguistic corpus-based models (Kenett, 2019).

Research using network methods allow examining how the structure of ones' semantic memory structure facilitates creative search processes. For example, in He et al. (2021), we estimated individual-based SemNets of a large sample, including measuring DT and associative thinking. We found that associative thinking mediated the relationship between SemNet efficiency and DT. In other words, higher creative individuals could search through their semantic memory more fluently, and make more distant semantic associations, because they possessed a more richly connected SemNet. In a recent study (Ovando-Tellez, Benedek et al., 2022), we took this research direction a step forward: We examined the relation of individual-based SemNet structure, neural functional connectivity analysis, and individual differences in creativity (both divergent and convergent creativity tasks), to a polysemous fluency task (generate what ever you can think of to a polysemous word). This study enabled a better characterization of the cognitive and neural mechanisms related to creative search. Specifically, it allowed us to identify how different aspects of creative search (e.g., exploration vs. exploitation) relates to different aspects of creative thinking (e.g., convergent vs. divergent), as well as how search is a goal-directed attention-based process. These findings indicate that while exploration reflects an interplay between controlled processes and SemNet structure, exploitation reflects controlled processes relevant to exhaustive memory search. Finally, we find that exploration was related to convergent thinking, while exploitation was related to divergent thinking (Ovando-Tellez, Benedek et al., 2022).

Research using linguistic corpus-based models provide an objective measure of semantic distance, that can be utilized to study creative search. Recent years have seen an explosion of studies of conceptual representation that take advantage of the widespread availability both of massive natural language corpora and of increased computational power (Kumar, 2021). These distributional semantics approaches yield large scale, data-driven, high-dimensional semantic spaces of concepts that characterize natural language and explain many aspects of behavioral, such as semantic similarity, semantic priming, and creativity (Beaty & Johnson, 2021; Mandera, Keuleers, & Brysbaert, 2017). Based on these models, semantic distance is computed as the inverse of semantic similarity. It has strong theoretical links to the associative theory of creativity, as it offers an objective way to quantify novelty of associations (Beaty & Johnson, 2021; Dumas, Organisciak, & Doherty, 2021; Kenett, 2019). We directly explore this link via a metric we developed termed forward flow (Gray et al., 2019), quantified over participants performance in a chain free association task. The chain free association task presents participants with a cue word, then prompts them to say the first word that comes to mind for each successive word they produce. Next, the semantic distance between the cue word and all subsequently generated words is calculated, capturing how far people travel in semantic space when freely associating. Forward flow was found to correlate with DT across various groups, as well as higher in exceptionally creative artists compared to scientists (Beaty, Zeitlen, Baker, & Kenett, 2021; Gray et al., 2019; Merseal et al., 2023). Thus, we argue it offers a method to empirically study how one searches their memory (Kenett et al., 2020).

Overall, such computational approaches are applied in increasing amount of research on the role of associative thinking in creativity. In a recent review of ours, we discuss both free- and goal-directed associative abilities in creativity, as well as cognitive and neural research on this topic (Beaty & Kenett, 2023). The general picture emerging from this review is: Higher creative individuals are better able to navigate their semantic memory: they travel further when associating (Beaty, Zeitlen, Baker, & Kenett, 2021; Gray et al., 2019), switch between more semantic subcategories (Zhang et al., 2022), and make larger "leaps" between associations (Olson, Nahas, Chmoulevitch, Cropper, & Webb, 2021).

In a complementary line of studies related to this current research, I examine the relation between associative thinking and creativity from the other direction: if higher creative individuals are more associative in their thinking, can we predict how creative a person is, simply by examining how they search their memory? I examine this issue by operationalizing performance in a semantic fluency task (in one minute, name all the animals you can think of) as a mental navigation process over memory (Benigni, Dallabona, Bravi, Merler, & De Domenico, 2021). Such a search process is modeled over a cognitive multiplex network – a cognitive network that has more than one layer (e.g., phonology, semantics, see Stella et al., 2024). Current research from my lab highlights how a cognitive multiplex network model can be used to accurately and successfully predict personality traits (Samuel, Stella, Beaty, & Kenett, 2023) and creativity (both DT and self reports; e.g., Stella & Kenett, 2019). Thus, this work highlights the transformative aspects of such creative search research.

As argued by the associative theory of creativity, our ability to search our mind plays a critical role in creativity. Our current ability to quantitatively operationalize and empirically study it opens many new and exciting lines of research.

The future: evolving

In new lines of research I am currently developing, I am focusing on the dynamics of semantic memory, examining how semantic memory evolves and shaped by problem-solving, learning, and time. For example, during my postdoctoral fellowship, I examined the dynamic nature of semantic memory structure, by studying how the way in which we use concepts (i.e., different ways of combining concepts) in turn affects the structure of semantic memory (Kenett & Thompson-Schill, 2020). I estimated group-based SemNets before and after a conceptual combination task, demonstrating differential effect of conceptual combination strategies on the post-manipulation SemNet. This study provides a novel quantitative perspective on a phenomenon that has been only studied via behavioral and neurocognitive means, and further advances current theories on the dynamic nature of semantic memory (Yee & Thompson-Schill, 2016). Further examples of this line of work includes examining the effect of traditional and non-traditional schooling systems on children's semantic memory (Denervaud, Christensen, Kenett, & Beaty, 2021), the effect of typical aging on semantic memory (Cosgrove, Beaty, Diaz, & Kenett, 2023; Cosgrove, Kenett, Beaty, & Diaz, 2021), and how successfully solving insight problems leads to semantic memory restructuring that has down-stream cognitive implications (Bieth et al., 2021). Specifically, in Bieth et al. we estimated individual-based SemNets before and after participants attempted to solve difficult riddles. These networks represented twenty concepts – ten related to the solution of the riddle and ten that are not. We find that only successful solvers exhibit focused, local semantic memory restructuring (Schilling, 2005; Wiley & Danek, 2024), exhibited by changes in network metrics related to the solution-related terms. Such SemNet restructuring in successful solvers was also related to participants creativity, such as DT.

Another main direction of inquiry focuses on information-seeking behavior (Kenett, Humphries, & Chatterjee, 2023). This line of work includes advancing empirical research on question-asking. While question-asking has traditionally been advocated in education research, it plays a significant role in problem solving and creative thinking. Such information seeking behavior likely promotes *problem finding*, the first stage in the creative problem-solving process (Reiter-Palmon & Robinson, 2009). Operationally, it involves the identification of a problem or the definition of an ambiguous situation into a workable problem or the raising of questions from ill-defined problem situations (Getzels, 1979). Past research indicates that problem finding is positively related to creative problem-solving (Mumford, Medeiros, & Partlow, 2012) and to DT (Alabbasi, Acar, & Reiter-Palmon, 2023). Reiter-Palmon, Mumford, O'Connor Boes, and Runco (1997) have found that people who excel at problem-finding tend to restate problems as questions, highlighting the significance of questions in creativity. Questions are essential in human interactions, from children to adults (De Simone & Ruggeri, 2021). Questions support our efforts to acquire knowledge and solve problems (Gottlieb, 2021; Rothe, Lake, & Gureckis, 2018). Thus, questions may realize problem finding, which in turn leads to problem solving. Despite the significance of question asking, it is surprising how scarce cognitive research there is on this critical ability.

In one line of research, we conducted an exploratory data analysis on the questions asked by an online question-asking game known as the Akinator (Sasson & Kenett, 2023). In this game, a Genie like character attempts to guess the character the human player is thinking of, by asking a series of yes/no questions. We examined the types and sequencing of questions asked by the Akinator, to gain insights into natural human question-asking. While our analysis was limited in scope due to IP protection, we demonstrate that the Akinator's question asking process does not aim to narrow an information space – a popular theory on the aim of question-asking – and that the questions generated by the Akinator can be characterized into focused, yet time-evolving, topics.

In a second line of research, we directly examine the role of asking more complex questions in creativity (Raz, Reiter-Palmon, & Kenett, 2023), by an adapted version of the AUT (Acar & Runco, 2019). In our revised task – the alternative questions task (AQT) – participants are presented with common objects such as a pencil or pillow, and are required to generate all the possible questions they can ask about that object. In a series of studies, we had participants undergo the AQT and the AUT. We then use subjective and objective assessments of participant's creative performance in both tasks, as well as rate each of the AQT questions for their complexity (based on a classic questions complexity taxonomy known as the Bloom taxonomy; Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). We find that as participants ask more complex questions, they are more creative, empirically highlighting the role of question asking in creativity (Raz, Reiter-Palmon, & Kenett, 2023). These results highlight the role of questions in creativity; and how the AQT can be used to shed novel light on this issue, such as how question asking might facilitate SemNet restructuring, or be related to other aspects of information-seeking behavior such as curiosity (Raz & Kenett, 2024). To facilitate the empirical research of question-asking in creativity, we have recently trained a large language model to automatically score the complexity of questions in the AQT (Raz, Luchini, Beaty, & Kenett, 2024).

Thus, methodological advancements and insights gained on semantic memory structure and the processes that operate on it are providing the way to quantify how knowledge evolves and the effect of such evolution on high-level cognition. Such research has significant general transformative potential, as it relates to other cognitive domains, such as learning, development, and aging.

Conclusions

My past, current, and future research focuses on the role of knowledge (semantic memory) in high-level cognition – such as creativity, associative thinking, and memory search – in typical and clinical populations, at the cognitive and neural levels. To conduct this research, I apply computational methods from network science, natural language processing, and machine learning, together with empirical cognitive and neural research. Another main characteristic of my current and future research is conducting research that bridges cognitive and neural levels of analysis, as well as focusing on dynamics of cognitive and neural systems and how such dynamics realize high-level cognition.

Overall, my research has consistently highlighted the role of a more flexible SemNet structure in creative thinking, provided novel insights on the role of search processes operating over semantic memory in creativity, and is pushing to elucidate the impact of SemNet evolution. Yet, every step forward opens multiple new lines of potential research under this scope, such as: What are the causal relations between SemNet structure and creativity? Can enriching SemNet structure have a direct impact on creativity? What are the roles of additional memory systems, such as episodic memory, in creativity (Benedek, Beaty, Schacter, & Kenett, 2023)? How does information-seeking behavior impact SemNet structure which in turn impacts creativity? How do executive processes interact with semantic memory to facilitate creative ideation (Kenett, Gooz, & Ackerman, 2023; Volle, 2018)? Regarding these questions, and many other great questions I have gotten over the years, my typical answer is: "this specific question has not been empirically investigated yet, but we now have the tools to do so." We are in a truly exciting time for creativity research, rapidly incorporating state-of-the-art computational tools. As such research is generally propelling creativity research forward (Lloyd-Cox, Pickering, Beaty, & Bhattacharya, 2023), it is uniquely allowing us to ask – in ways that were impossible before – what is the role of knowledge in creative thinking.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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