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Creativity, the fountain of youth: Association between creativity and semantic memory networks across the lifespan

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ABSTRACT

Creativity relies on the ability to make new associations between concepts stored in our semantic memory in order to create new and effective ideas in a specific context. Recent studies showed that creative people are characterized by more flexible semantic memory structures, which facilitate novel associations between concepts. On the other hand, older adults exhibit more rigid semantic memory structures and ability to access these structures, raising questions about how the relationship between semantic memory networks and creativity may change with ageing. Can creativity support a more flexible reconstruction of semantic memory network during ageing? To investigate this, 77 older adults ($M = 77.8$ years, $SD = 4.63$) and 81 younger adults ($M = 20.3$ years, $SD = 1.71$) completed four verbal production tasks (i.e., two verbal fluency and two free association tasks), from which semantic memory networks were estimated. Moreover, two divergent thinking tasks (i.e., Alternative Uses Task) were used to assess creative performance. The results showed that the typical maturation of older adults' semantic memory network is associated with a decrease in creative performance in comparison to younger adults. On the other hand, higher creative older adults exhibited preservation of their overall semantic memory flexibility in comparison to lower creative older adults, similar to lower creative young adults. Overall, this study highlights the potential protective role of creativity in supporting active ageing through its propaedeutic role in maintaining a flexible organization and access to semantic memory structures.

1. Introduction

Ennio Morricone, the famous composer who wrote many of cinema history's most iconic soundtracks, composed the soundtrack of "The Hateful Eight" (Tarantino, 2015) when he was 87 years old. This work awarded him in 2016 the Oscar for Best Soundtrack and it was not even his last composition. Is it typical for creativity to be maintained or to flourish during ageing? How did Morricone manage to be so creative even at the ripe age of 87? What are the main cognitive factors that can sustain creative achievement and creativity expression during ageing?

Despite the decline in performance in several cognitive domains (Grady, 2012a, 2012b; Salthouse, 2010), including memory (Chalfonte & Johnson, 1996; Park et al., 2002), processing speed (Salthouse, 1996), executive functions (Ferguson et al., 2021), and language production abilities (Burke et al., 1987; Burke & Shafto, 2004), some domains (e.g., verbal abilities, autobiographical memory, emotional processing and automatic memory processes; Hedden & Gabrieli, 2004; Spreng & Turner, 2019) remain stable across the lifespan. In this regard, it remains unclear whether older adults consistently and universally experience a decline in creative performance as they age (for a review, see Fusi et al., 2021). This becomes relevant as creativity seems to be associated with beneficial effects on ageing (Price & Tinker, 2014), including higher levels of well-being (Freundlich & Shively, 2006; Lindauer, 2012; Zhang & Niu, 2013) and higher cognitive reserve (Fusi et al., 2024; Palmiero et al., 2016).

Creativity is a multidimensional construct (Sternberg & Lubart, 1996) that is based on the ability to produce original and effective content in a specific context at a given time (Amabile, 2019; Runco &

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Jaeger, 2012; Stein, 1953). It is considered a key feature for coping with change, innovation, and adapting to the environment, shaping everyday life and cultural, economic, and scientific advancements (Hennessey & Amabile, 2010). In recent literature, creativity has been explained as the result of the dynamic interplay between associative, spontaneous and automatic processes with controlled, goal-directed and deliberate processes (Chen et al., 2025; Nijstad et al., 2010; Zhang et al., 2020). Associative abilities refer to the ability to re-combine weakly related concepts into novel and effective content (Beaty & Kenett, 2023; Kenett, 2025; Kenett & Faust, 2019; Mednick, 1962), while control processes serve as a monitoring force during the associational phase, ensuring that the recombinational process follows the goal and constraints of the engaged creative process (Beaty & Silvia, 2012; Benedek, Franz, et al., 2012; Nusbaum & Silvia, 2011). Consistently, several evidence coming from neurocognitive research support this two-stage dynamic of the creative process, showing increased cooperation between the default mode network and the executive control network during a creative task (Beaty et al., 2016; Benedek & Fink, 2019). Therefore, according to this perspective, creativity arises from the interplay between bottom-up, associative abilities, and top-down, controlled processes (Barr et al., 2015; Chen et al., 2025).

In line with the dual-process perspective of creativity, the default-executive coupling hypothesis of ageing (DECHA; Turner & Spreng, 2015) was proposed. During ageing, older adults tend to experience a decline in their level of executive function abilities. However, according to the DECHA framework, this decline in the controlled, goal-oriented system would be counteracted by higher access to prior knowledge representations (Spreng et al., 2018; Spreng & Turner, 2019). This developmental compensatory mechanism has been identified by the authors in a semanticization of the cognitive processes and it has been associated with creative cognition as well. According to this framework, during ageing, the creative process should become less dependent on the top-down executive system in favor of the associative, bottom-up system. This developmental trajectory seems to be supported by both neurocognitive evidence - pointing at a higher coupling between the default and the executive networks in older adults (Adnan, Beaty, Lam, et al., 2019; Adnan, Beaty, Silvia, et al., 2019) – and behavioral evidence (Colautti et al., 2023; Raz et al., 2025). In a recent study, Cosgrove et al. (2025) found that the relationship between age and creative abilities was mediated by fluid intelligence and vocabulary size (Cosgrove et al., 2025). Thus, according to this perspective, older adults are characterized by richer vocabulary knowledge (Cosgrove et al., 2023) that seems to counteract the executive decline and support flexible idea generation.

However, it is unlikely that only the size of one's vocabulary can sustain flexible and effective associative thinking. For instance, according to the associative theory of creativity (Mednick, 1962), associative abilities are related to how people organize and combine concepts stored in their memory (Beaty & Kenett, 2023). According to this perspective, associative abilities sustain the creative thinking process not only relying on the vocabulary size but especially on the organization and the ability to control the navigation inside the semantic memory structure (Hills & Kenett, 2022; Kenett, 2025). Semantic concepts can indeed be intended as the building blocks for creative recombination (Abraham & Bubic, 2015), and how they are mapped and recollected is crucially influencing the creative process (Hills & Kenett, 2025). Therefore, according to this perspective, vocabulary organization into semantic memory structures and the ability to control the navigation inside this structure become central for the understanding of creative performance, more than just the vocabulary size. In other words, creative abilities are the result of the way in which semantic memory is mapped and accessed by the individual. This view is in line with the map and vehicle framework (Hills & Kenett, 2022), in which semantic memory structure represents the map onto which the vehicle (i.e., the controlled navigation process) explores semantic memory. Despite this centrality in the creative process, the role of the structure and recollection of concepts from semantic memory during ageing has yet to be fully understood.

1.1. *Semantic memory networks, creativity and ageing*

Recently, the application of computational network science allows researchers to better investigate structure and access to semantic memory. Network science, based on mathematical graph theory, provides quantitative methods to investigate complex systems as networks (Baronchelli et al., 2013; Siew et al., 2019), including cognitive functions, such as language (Beckage & Colunga, 2016; De Deyne et al., 2013; Hills et al., 2009), statistical learning (Karuza et al., 2017), and semantic memory (Hills & Kenett, 2022; Siew et al., 2019). In the past few years, several studies demonstrated a consistent association between semantic memory networks and creative performance (Benedek et al., 2017; Kenett et al., 2014; Kenett & Faust, 2019), shedding light on the relationship between idea generation and semantic memory structure and access. Specifically, creative individuals' semantic memory networks are characterized by lower semantic distance between concepts, higher connectivity and less segregated modules (Kenett, 2025; Kenett & Faust, 2019). The same pattern of network properties was also found to be associated with higher convergent thinking and insight performance (Luchini et al., 2023), which is an integral part of the creative process (Cropley, 2006), metaphor production (Li et al., 2021), higher openness to experience (Christensen, Kenett, Aste, et al., 2018; Christensen, Kenett, Cotter, et al., 2018) and real-life creative behaviour at the individual level (Ovando-Tellez et al., 2022). Furthermore, creative individuals exhibit semantic memory networks that are more resistant to selective "attacks", thus being more flexible (Kenett et al., 2018a, 2018b). Altogether, these results suggested that creative people are characterized by more flexible, condensed and connected semantic memory networks. This type of organization is considered to facilitate a more efficient spreading of information in the networks, enhancing the possibility of remote associations, ending up in higher creative ideation (Kenett, 2025).

However, several questions are still open for the understanding of the relationship between semantic memory and creativity, especially if we take into account the developmental trajectories of memory across the lifespan. Recent studies on semantic memory networks reported variations in semantic memory organization properties across the lifespan, cross-sectionally comparing the structure of semantic memory networks across age cohorts (Cosgrove et al., 2023; Dubossarsky et al., 2017; Wulff et al., 2022).

Dubossarsky et al. (2017) showed a structural development dynamic of semantic memory across the lifespan. The study showed that children display semantic memory organizations characterized by high modularity and segregation, followed by an increase in flexibility and density towards midlife, returning to a condition of high segregation among older adults (Dubossarsky et al., 2017). In other terms, the authors found that semantic memory network properties evolve in a non-linear (U-shaped) modality, suggesting that older adults' networks "lose coherence" over time, thus affecting memory retrieval while still expanding their vocabularies.

Cosgrove and colleagues analyzed differences between younger and older adults by using percolation analysis, a computational approach measuring the resiliency of complex networks by progressively removing nodes or edges to test network flexibility (Borge-Holthoefer et al., 2011; Cosgrove et al., 2021; Kenett et al., 2018a, 2018b; Stella, 2020). This study found that older adults' networks "broke apart" faster compared to their younger counterparts, suggesting diminished network flexibility and resiliency for older adults (Cosgrove et al., 2021). Altogether, these findings suggested that older adults are characterized by less connected, more segregated and less flexible semantic memory networks compared to young adults, raising questions on the effects that such organization could have on creativity. Does for instance the typical ageing segregation of semantic memory structures impact creative performance? Or, instead, could a preservation of semantic memory networks in old age be related to higher creative performance?

1.2. The present study: aims and hypotheses

Indeed, research demonstrated that the semantic memory networks of higher creative individuals are less spread out, less segregated (Benedek et al., 2017; Kenett et al., 2014, 2016; Ovando-Tellez et al., 2022) and more flexible (Kenett et al., 2018a, 2018b) compared to lower creative individuals. On the other hand, studies focusing on semantic memory organization in ageing point out that older adults tend to show a pattern of structural semantic memory properties which is similar to the one found in lower creative individuals (Cosgrove et al., 2021; Dubossarsky et al., 2017; Wulff et al., 2022), suggesting, as a consequence, that the typical ageing maturation of semantic memory organization could be associated with a decrease in creativity. The present study aims to address multiple questions related to the association between semantic memory networks and creative performance, measured through divergent thinking (i.e., the ability to generate multiple solutions in response to a given stimulus or problem; Guilford, 1967), in younger and older adults. In particular, we aim to investigate through computational network science methods (i.e., network estimation, network analysis, and percolation analysis): if (hypothesis 1) the typical rigidification and segregation of older adults' semantic memory networks are associated with a decrease in creative performance in terms of originality of ideas in a divergent thinking task; If (hypothesis 2) the typical differences in semantic memory networks in higher vs. lower creative individuals showed for younger adults could also emerge when comparing the networks of higher vs. lower creative older adults; Lastly, whether (hypothesis 3) the semantic memory networks of higher creative older adults may display a semantic organization that is similar to younger adults, suggesting a potential role of creativity in maintaining semantic memory network flexibility in ageing.

2. Method

2.1. Participants

All participants were healthy, native Italian speakers with no history of neurological or physiological disorders and no major medical condition (e.g., cancer, diabetes, heart disease). The older adult sample underwent a neuropsychological screening test to rule out potential cognitive impairments that could have biased the data. For this purpose, the Italian version of the Mini-Mental State Evaluation (MMSE; Folstein et al., 1975; Frisoni et al., 1993) was used. In order to be included in the study, older adults had to reach a cut-off score of 26 out of 30.

Through power analysis run in the G*power software (Faul et al., 2007), based on the effect size that emerged in Cosgrove et al. (2021) and taking into account the number of predictors in our models, we estimated that a minimal sample size of 70 participants for each age group would be sufficient to observe an effect of $f = 0.44$ with a 0.95 power (critical $F = 3.97$) (Cohen, 2013; Lakens, 2013). The data was collected from 81 younger adult psychology students (mean age = 20.3 years, $SD = 1.71$, females = 69) at the University of Trieste and from 79 older adult participants (mean age = 77.8 years, $SD = 4.63$, females = 64), with two excluded participants who fell below the threshold of the MMSE cut-off score. The older adult population was recruited at the Associazione Ricerca Interventi Studi in Trieste. All participants, who freely volunteered to participate in the study, signed an informed consent. The research was approved by the University of Trieste Ethical Committee (protocol n. 137).

2.2. Materials

2.2.1. Alternative Uses Task

Participants completed the Alternative Uses Task (AUT; Guilford, 1967), a widely used measure of divergent thinking. Divergent thinking is the exploratory thinking ability that aims to produce multiple alternative solutions to an open problem (Acar & Runco, 2019), i.e., the ability to think in many different directions (Taylor, 1988), which is considered a reliable predictor of creative potential (Runco & Acar, 2012). The task requires participants to produce as many original alternative uses as possible for a target object (e.g., a brick) in a given time (i.e., 3 min). Specifically, participants saw two objects (i.e., shoe and fork) in a written form and were instructed to orally produce their responses. Participants were asked to produce original alternative uses for three minutes for each object, which guaranteed a sufficient production time also for the older participants (Foos & Boone, 2008; Leon et al., 2014). For each participant, fluency and originality scores were then computed. Fluency was computed as the number of total responses given by a participant. Originality was calculated using the OCSAI (Open Creativity Scoring with Artificial Intelligence) scoring system, which fine-tuned deep neural network-based large-language models (LLMs) on human-judged responses, automating AUT originality scoring (Organisciak et al., 2023).

Based on the mean originality scores of each participant, each age group (i.e., younger adults and older adults) were median split into a high creativity group and a low creativity group, resulting in four target groups: a) Higher creativity younger adults (HCYA), b) Higher creativity older adults (HCOA), c) Lower creativity younger adults (LCYA), and d) Lower creativity older adults (LCOA).

2.2.2. Fluency tasks

In order to model semantic memory networks, participants were asked to complete two different verbal production tasks: a semantic fluency task and a free association task. The semantic fluency task is a categorical fluency task in which one is asked to produce items belonging to a semantic category (e.g., animals) in a given time. The task is an efficient way to investigate the ability to retrieve semantic information from long-term memory (Bousfield et al., 1958; Goñi et al., 2011; Patterson, 2011), also used in modelling group-based semantic memory networks (Siew et al., 2019). Participants completed two verbal fluency tasks with two different target categories (i.e., animals and vegetables/fruits) with 60 s timing each.

The second verbal production task was a free association task in which participants were asked to generate as many associative responses to a target word (Nelson et al., 2000). Compared to the verbal fluency task, this method allows the exploration of a greater part of the mental lexicon, getting closer to the actual semantical navigation inherent to the creative process (De Deyne et al., 2013; Kenett et al., 2011). Again, participants completed two association tasks with two different target words (i.e., notebook and building) with a 60 s time limit. The presentation order of the verbal production tasks was randomized.

2.3. Network estimation and analysis

According to network science theory, a network is composed of nodes (i.e., the basic unit of the system) and edges (i.e., the connections between units) that represent the relations between nodes (Baronchelli et al., 2013; Borge-Holthoefer & Arenas, 2010; Steyvers & Tenenbaum, 2005). Several methods exist to define and measure the functional and structure organization of a network (for a review, see Siew et al., 2019), but we can identify at least three main measurable features of a network: average shortest path length (ASPL), clustering coefficient (CC) and modularity (Q). ASPL represents the index of the average shortest number of steps (i.e., edges) to travel between any pair of nodes. In this sense, ASPL is the formalization of the grade of relatedness of two nodes. The higher the ASPL, the more the network is spread out. CC is the index of the probability that the neighbor of a node would be, in turn, a neighbor, which indicates how well the neighboring nodes of a node are connected to each other. In other words, CC represent the level of interconnectivity of the network. Lastly, Q is the index of the tendency of the network to break apart in sub-communities inside the network. So, the higher the Q, the more the network is segregated (for a review see, Fortunato, 2010; Siew et al., 2019). Cognitively speaking, comparing these parameters between different networks gives researchers the ability to shed light on the organization and dynamics of different cognitive mechanisms, both at the group (Christensen, Kenett, Cotter, et al., 2018; Kenett et al., 2014) and at the individual level (Benedek et al., 2017; Ovando-Tellez et al., 2022).

Verbal production data of all groups was analyzed using a semantic memory network approach (Christensen & Kenett, 2023) in which each node represents a concept (e.g., apple) and edges represent the association between two concepts, namely the tendency to produce the concept *b* (e.g., red) when also *a* (e.g., apple) was generated. Starting from this perspective, the network analyses were conducted in R using different publicly available pipelines, such as *SemNet* (Christensen & Kenett, 2023) and *CliquePercolation* (https://CRAN.R-project.org/package=CliquePercolation).

2.3.1. Network estimation

As the first step, verbal production data was transcribed and translated from Italian to English in order to preprocess it with the R packages *SemNetDictionaries* and *SemNetCleaner* (Christensen & Kenett, 2023). These packages automatically correct spelling errors, compound responses (two responses in which the space is missing), variations on the root (e.g., apples to apple) and continuous strings (multiple responses entered as a single response) and then transfer the corrected responses into a binary response matrix. The matrix is composed of columns representing all the exemplars (i.e., words) produced by the groups and the rows representing participants. If a participant produced the exemplar, the cell will be filled with 1, otherwise with a 0.

Next, the *SemNet* package (Christensen & Kenett, 2023) was used to compute the associations between the verbal responses. For this estimation, the correlation-based network method was implemented, a method based on the co-occurrence of responses across the response matrix using the cosine similarity function (Christensen, Kenett, Cotter, et al., 2018). As a filtering method, we adopted the Triangulated Maximally Filtered Graph (TMFG), which is able to create different networks with the same number of nodes and edges (Massara et al., 2016). TMFG is also recommended to maximize the strength of the association between the nodes while maintaining the network planar to be optimally represented graphically (Christensen, Kenett, Aste, et al., 2018).

2.3.2. Network analyses

In order to estimate the measures to compare the networks of the four target groups (i.e., HCYA, HCOA, LCYA and LCOA), a bootstrapping approach was used (Efron, 1979). In particular, the node-wise approach with 50 % of each group dataset with 1000 iterations was adopted. This method consists of an estimation of the networks starting from a subset of the nodes and is based on the assumption that if the full networks differ from each other, then also the partial networks composed of the same nodes should differ (Bertail, 1997; Politis & Romano, 1994; Shao, 2003). Starting from this sampling distribution, ASPL, CC and Q were computed for each network and then compared with ANOVA and *t*-test comparisons. For more information about network estimation and comparison analyses, see Christensen and Kenett (2023), or Epskamp et al. (2018).

2.3.3. Percolation analysis

Moreover, a percolation analysis was performed using the *CliquePercolation* package in R (https://CRAN.R-project.org/package=CliquePercolation), following and adapting a publicly available code (for more information see: Cosgrove et al., 2021). This analysis was used to probe the resilience, or flexibility, of the different group-based networks under targeted attacks (Farkas et al., 2007; Palla et al., 2005) by progressively removing edges that are below a certain threshold of intensity (which was defined, in our case, by the cosine similarity measure of association) for each percolation step. In order to do this, for each percolation step, the size of the Largest Connected Component (LCCS), which represents the largest cluster of nodes connected to each other, was measured. For every percolation step, the threshold of intensity (*I*), which ranges from 0 to 1, is increased by 0.01, calculating the index of LCCS for each step. In this way, the networks will go from totally intact (i.e., the minimum threshold, $I = 0.01$) to totally fragmented (i.e., maximum threshold, $I = 1$). After this computation, the percolation integral for each group was calculated. The percolation integral is the area under the curve representing the percolation steps, and lower indexes represent faster breaking apart of the network. This process was conducted for 500 iterations for each network. Then percolation integrals were compared by running a two-way ANOVA, with age (young vs. old) and creativity level (high vs. low) as independent variables. Data and analysis code are available at https://osf.io/9cyua/?view_only=dae90b0880984e1796f5cdceccba5853

2.4. Procedure

The study took place in a quiet room free from acoustic and visual distractors. Participants were asked to sit on a chair in front of a desk. One of the researchers briefly explained the aim of the study and its design before starting the data collection. Firstly, older adults were asked to complete the Mini-Mental State Evaluation (MMSE; Folstein et al., 1975; Frisoni et al., 1993) by answering orally to the verbal tasks and by using paper and pencil in the figurative tasks. If the cut-off was reached, older adults started the actual experimental design. As a first step, participants were instructed to orally complete the verbal production tasks by saying out loud their responses. The target words were presented in a written and printed format and the order of presentation of the Verbal fluency task and the Free association task was randomized. Then, they were asked to complete the AUT by saying out loud their alternative responses. The AUT objects were presented in a written and printed format. All the target stimuli were placed on the desk in front of the participants and remained visible throughout the entire duration of each task. All participants' responses to the tasks were recorded through an audio recorder and then transcribed in an electronic sheet by one of the experimenters.

3. Results

3.1. AUT results

To test whether AUT performance varied across the groups, a two-way ANOVA was performed to evaluate the effects of the age group, creativity level, and their interaction on the mean response originality (Table 1). The analysis showed a significant main effect of age, $F(1, 154) = 151.4$, $p < .001$, $\eta^2p = 0.496$; a significant main effect of creativity level, $F(1, 154) = 79.2$, $p < .001$, $\eta^2p = 0.340$; and a significant interaction between age and creativity level, $F(1, 154) = 25.6$, $p < .001$, $\eta^2p = 0.142$. Younger adults in particular emerged as more original than older adults, $t(154) = 12.3$, $p < .001$, $d = 1.96$, whereas the higher creativity group was more original than the low creativity group, $t(154) = 8.90$, $p < .001$, $d = 1.42$.

As depicted in Fig. 1, the higher creativity younger adult (HCYA) group showed higher mean originality compared to the higher creativity

Table 1
Mean and SD originality for the four groups.

	HCYA	HCOA	LCYA	LCOA
Mean Originality	3.05	2.85	2.69	2.07
SD	0.21	0.23	0.26	0.40

Notes: HCYA = Higher creative Younger Adults; LCYA = Lower Creative Younger adults; HCOA = Higher Creative Older Adults; LCOA = Lower Creative Younger Adults.

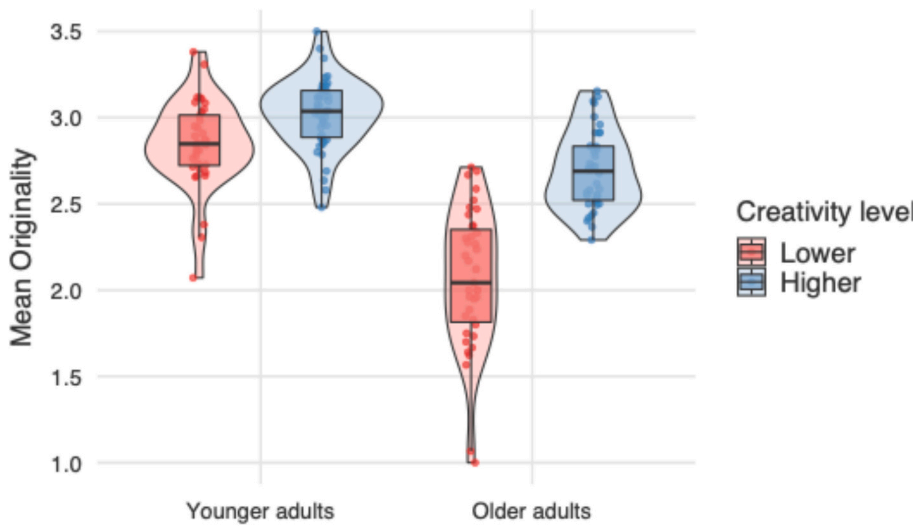

Fig. 1. AUT mean originality distribution across age (younger vs. older) and level of creativity (higher vs. lower).

older adult (HCOA) group, $t(154) = 5.25$, $p < .001$, $d = 1.16$, the lower creativity younger adult (LCYA) group, $t(154) = 2.74$, $p = .034$, $d = 0.61$, and the lower creativity older adult (LCOA) group, $t(154) = 15.47$, $p < .001$, $d = 3.39$. Moreover, the HCOA group showed higher mean originality than LCOA, $t(154) = 9.78$, $p < .001$, $d = 2.29$, and no significant difference compared to LCYA, $t(154) = -2.34$, $p = .094$, $d = 0.54$. Lastly, the LCYA showed higher mean originality scores compared to LCOA, $t(154) = 11.99$, $p < .001$, $d = 2.77$.

3.2. Semantic memory networks: structural and percolation results

First, through the network estimation process we extracted the three network measures (i.e., ASPL, CC and Q) for each group (Table 2) and produced a 2D graphical representation of the network (Fig. 2). Secondly, a random network analysis was performed to exclude that the difference between the groups derived from a null hypothesis (Christensen & Kenett, 2023). This method allows for testing whether the group network measures differ from a random network with the same number of nodes and edges. This analysis showed that all four groups' network measures were significantly different from their random counterparts (all p's < 0.001), rejecting the null hypothesis.

Then, a bootstrap partial network analysis was used to statistically examine the differences between the four groups (Bertail, 1997; Christensen & Kenett, 2023; Kenett et al., 2014). The analysis generates a distribution of values – using a 1000 sample distribution - for each network measure (i.e., ASPL, CC and Q) for each of the four networks (i.e., HCYA, LCYA, HCOA, LCOA). A 2 × 2 ANOVA was conducted to test the differences between the bootstrap partial networks of the four groups, using the age group and the creativity level as independent variables and testing the effect of their interaction as well. Further analyses (using different numbers of bootstrap iterations and percentages of nodes for the measures estimations) are included in the Supplementary Materials.

Table 2
Estimated network measures for the four groups.

Network measure	Higher Younger	Higher Older	Lower Younger	Lower Older
ASPL	2.83	3.02	3.06	3.67
CC	0.77	0.75	0.76	0.73
Q	0.59	0.61	0.67	0.62

Notes: ASPL = Average Shortest Path Length; CC = Clustering Coefficient; Q = Modularity.

3.2.1. Average shortest path length (ASPL)

Analyses revealed a significant main effect of age, $F(3, 3996) = 3133.63$, $p < .001$, $\eta^2p = 0.35$, a significant main effect of creativity level, $F(3, 3996) = 1756.59$, $p < .001$, $\eta^2p = 0.33$, and a significant interaction between Age and Creativity level, $F(3, 3996) = 62.01$, $p < .001$, $\eta^2p = 0.10$. Post-hoc paired-samples t-test analyses (Table 3) revealed that the HCYA group showed significantly lower ASPL compared to the LCYA group, the HCOA group, and the LCOA group. Moreover, the HCOA group showed lower ASPL in comparison to the LCOA group, and no significant difference compared to the LCYA. Finally, the LCYA group showed significantly lower ASPL compared to the LCOA group.

3.2.2. Clustering coefficient (CC)

Analyses revealed a significant main effect of age, $F(3, 3996) = 5040.4$, $p < .001$, $\eta^2p = 0.37$, a significant main effect of creativity level, $F(3, 3996) = 2373.1$, $p < .001$, $\eta^2p = 0.56$, and an interaction between Age and Creativity level, $F(3, 3996) = 154.8$, $p < .001$, $\eta^2p = 0.04$. Post-hoc paired-samples t-test analyses (Table 4) revealed that the HCYA group showed significantly higher CC compared to the LCYA group, significantly higher than the HCOA group, and the LCOA group. The HCOA group showed significantly higher CC compared to the LCOA group, but lower CC compared to the LCYA group. The LCYA group showed significantly higher CC compared to the LCOA group.

3.2.3. Modularity (Q)

Finally, analyses revealed a significant main effect of age, $F(3, 3996) = 3133.63$, $p < .001$, $\eta^2p = 0.44$, a significant main effect of creativity level, $F(3, 3996) = 1756.59$, $p < .001$, $\eta^2p = 0.31$, and an interaction between Age and Creativity level, $F(3, 3996) = 62.01$, $p < .001$, $\eta^2p = 0.02$. Post-hoc paired-samples t-test analyses (Table 5) revealed that the HCYA group showed significantly lower Q compared to the LCYA group, the HCOA group, and the LCOA group. The HCOA group showed significantly lower Q compared to the LCOA group, and significantly higher Q but with a moderate effect size compared to the LCYA group. The LCYA group showed significantly lower Q compared to the LCOA group. Further analyses substantiating differences between groups with a different proportion of nodes considered or with fewer iterations in the bootstrap can be found in the Supplementary Material.

3.2.4. Percolation analysis results

The area under the curve and the percolation integrals of each group were analyzed to statistically compare the resiliency of each network. To test the comparison significance, 500 realizations of the percolation test

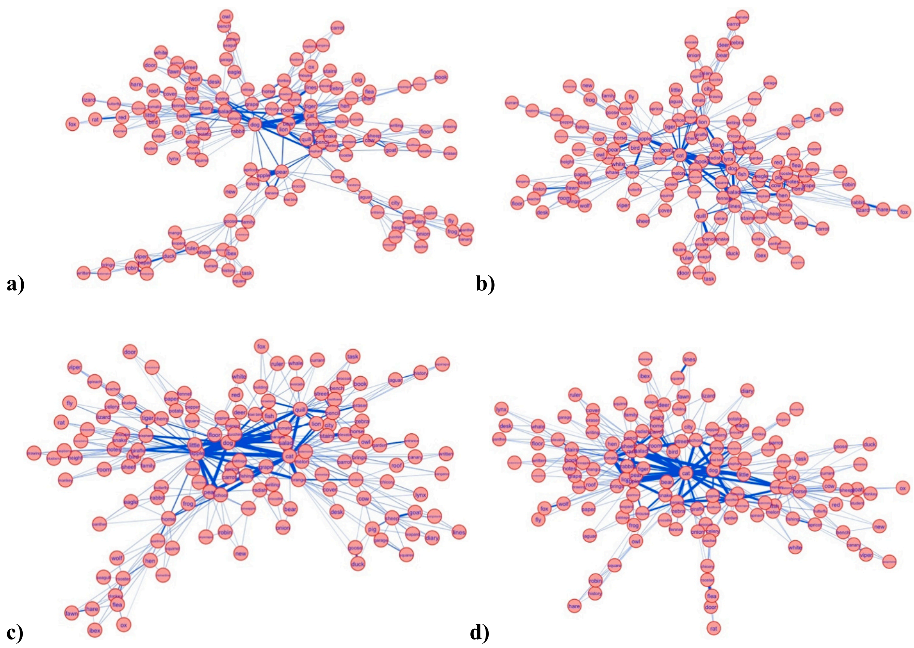

Fig. 2. 2D representation of the four network with nodes exemplars: lower (A) and higher (B) creativity in older adults, and lower (C) and higher (D) creativity in younger adults.

Table 3
ASPL Post-hoc paired samples *t*-test analyses, means and SDs.

		t-statistic	*p*-value	Mean1	SD1	Mean2	SD2	d
HCYA	LCYA	−20.96	< 0.001	2.46	0.08	2.55	0.10	0.94
	HCOA	−18.93	< 0.001	2.46	0.08	2.56	0.14	0.85
	LCOA	−65.17	< 0.001	2.46	0.08	2.81	0.14	2.91
HCOA	LCOA	−39.04	< 0.001	2.56	0.14	2.81	0.14	1.75
	LCYA	1.52	0.128	2.56	0.14	2.55	0.10	0.07
LCYA	LCOA	−45.32	< 0.001	2.55	0.10	2.81	0.14	2.03

Notes: HCYA = Higher creative Younger Adults; LCYA = Lower Creative Younger adults; HCOA = Higher Creative Older Adults; LCOA = Lower Creative Younger Adults.

Table 4
CC Post-hoc paired samples t-test analyses, means and SDs.

		t-statistic	*p*-value	Mean1	SD1	Mean2	SD2	d
HCYA	LCYA	28.41	< 0.001	0.77	0.01	0.76	0.01	1.37
	HCOA	42.58	< 0.001	0.77	0.01	0.75	0.01	1.90
	LCOA	85.67	< 0.001	0.77	0.01	0.73	0.01	3.83
HCOA	LCOA	39.73	< 0.001	0.75	0.01	0.73	0.01	1.78
	LCYA	−15.57	< 0.001	0.75	0.01	0.76	0.01	0.70
LCYA	LCOA	57.45	< 0.001	0.76	0.01	0.73	0.01	2.57

Notes: HCYA = Higher creative Younger Adults; LCYA = Lower Creative Younger adults; HCOA = Higher Creative Older Adults; LCOA = Lower Creative Younger Adults.

Table 5
Q Post-hoc paired samples t-test analyses, means and SDs.

		t-statistic	*p*-value	Mean1	SD1	Mean2	SD2	d
HCYA	LCYA	−26.08	< 0.001	0.49	0.02	0.52	0.02	1.17
	HCOA	−33.54	< 0.001	0.49	0.02	0.53	0.03	1.50
	LCOA	−75.36	< 0.001	0.49	0.02	0.57	0.02	3.37
HCOA	LCOA	−32.85	< 0.001	0.53	0.03	0.57	0.02	1.57
	LCYA	9.85	< 0.001	0.53	0.03	0.52	0.02	0.50
LCYA	LCOA	−45.81	< 0.001	0.52	0.02	0.57	0.02	1.94

Notes: HCYA = Higher creative Younger Adults; LCYA = Lower Creative Younger adults; HCOA = Higher Creative Older Adults; LCOA = Lower Creative Younger Adults.

were conducted. A two-way ANOVA was performed to evaluate the effects of age and creativity level on the distribution of percolation integrals between each semantic memory network. The analysis showed a significant main effect of age, $F(3, 1996) = 7071$, $p < .001$, $\eta^2 p = 0.78$, a significant main effect of creativity level, $F(3, 1996) = 8010$, $p < .001$, $\eta^2 p = 0.80$, and a significant interaction between age and creativity level, $F(3, 1996) = 1612$, $p < .001$, $\eta^2 p = 0.44$ (Fig. 3).

Post-hoc paired-sample *t*-test comparisons revealed that the younger adult group ($M = 62$, $SD = 2.28$) showed significantly higher average percolation integrals compared to the older adult group ($M = 55.7$, $SD = 4.62$), $t(1996) = 89.5$, $p < .001$, $d = 4.0$. The higher creativity group ($M = 61.8$, $SD = 2.43$) showed significantly higher average percolation integrals compared to the lower creativity group ($M = 55.9$, $SD = 4.79$), $t(1996) = 84.1$, $p < .001$, $d = 3.76$.

In particular, the HCYA group (M = 63.6, SD = 1.73) showed higher average percolation integrals compared to the HCOA group, $t(1996) = 34.89$, $p < .001$, $d = 2.21$, the LCYA group, $t(1996) = 31.07$, $p < .001$, $d = 1.97$, and the LCOA group, $t(1996) = 122.75$, $p \leq 0.001$, $d = 7.76$ (Fig. 3). Moreover, the HCOA group showed higher average percolation integrals compared to the LCOA group, $t(1996) = 87.85$, $p < .001$, $d = 5.56$, but lower average percolation integrals compared to the LCYA group, $t(3996) = -3.82$, $p < .001$, $d = 0.24$. Lastly, the LCYA group showed higher average percolation integrals compared to the LCOA group, $t(1996) = 91.67$, $p < .001$, $d = 5.80$.

4. Discussion

In this study, we examine the relationship between creative performance and semantic memory networks in two age cohorts, exploring how the relation changes across the lifespan. After splitting both age samples into higher and lower creative individuals according to divergent thinking performance scores, the semantic memory networks of younger and older adult groups were estimated and compared.

The results comparing semantic memory networks of younger higher and lower creative individuals were in line with previous studies confirming that higher creative individuals display more functionally organized and flexible semantic memory networks compared to lower creative individuals (Kenett, 2025; Kenett & Faust, 2019). Furthermore, the results also confirmed that younger adults demonstrate less spread out, less segregated and more flexible semantic memory networks compared to older adults (Cosgrove et al., 2021; Cosgrove et al., 2023; Dubossarsky et al., 2017; Wulff et al., 2022).

More importantly, this study highlighted how the typical maturation of semantic memory networks in older adults is associated with a decrease in creative performance, as measured by divergent thinking task (i.e., Alternative Uses Task; Guilford, 1967). However, higher level of creative performance in older adults was associated with higher preservation of semantic memory flexibility and functional organization, extending the consistency of the relationship across the lifespan. Lastly, and more interestingly, our results showed that comparing the semantic memory network properties of higher creative older adults and lower creative younger adults, the average shortest path length index remains stable in older adults, while connectivity and modularity remain more flexible in the younger group. These results suggest that higher creative performance in older adults is associated with a semantic memory structure that is comparable to the organization of the network of lower creative younger adults, suggesting a pivotal role of creativity in preserving the flexibility and overall efficiency of the semantic organization and access.

4.1. *Older adults' semantic memory rigidity is associated with lower creativity*

Going deeper into our results, consistent with previous research, we found that older adults exhibit a semantic memory network that is more spread out (i.e., higher ASPL), less interconnected (i.e., lower CC) and more segregated (i.e., higher Q) compared to younger adults (Cosgrove et al., 2021; Dubossarsky et al., 2017; Wulff et al., 2022). Overall, these properties reflect lower efficiency and flexibility of the older adults' network, highlighting a maturation dynamic of the semantic memory structure and access. Notably, older adults produced a higher number of unique responses across participants (see Supplementary material). Although these findings highlight the richness and diversity of older adults' vocabulary, this heterogeneity in the production results in a more segregated and less interconnected network (which however could also be partially related to the conservative nature of the triangulated maximally filtered graph used in the network filtering). The high diversity in older adults' productions is interpreted to be the result of lifelong experience (Hills, 2025; Jeong & Hills, 2024), ultimately leading to different structures and access to semantic memory.

Older adults' rigid organization was found to be associated with lower creative performance, suggesting a possible direct association between semantic memory structure and access rigidity and the decrease in creative performance. This decline in creative performance can be explained by the higher difficulty in "navigating" less organized and less flexible semantic structures to create original and remote associations between concepts (Beaty & Kenett, 2023; Benedek et al., 2023). In other words, older adults seem to have more difficulties in accessing concepts, due to both a rigidly organized structure and a lower ability to control the process, resulting in fewer building blocks on

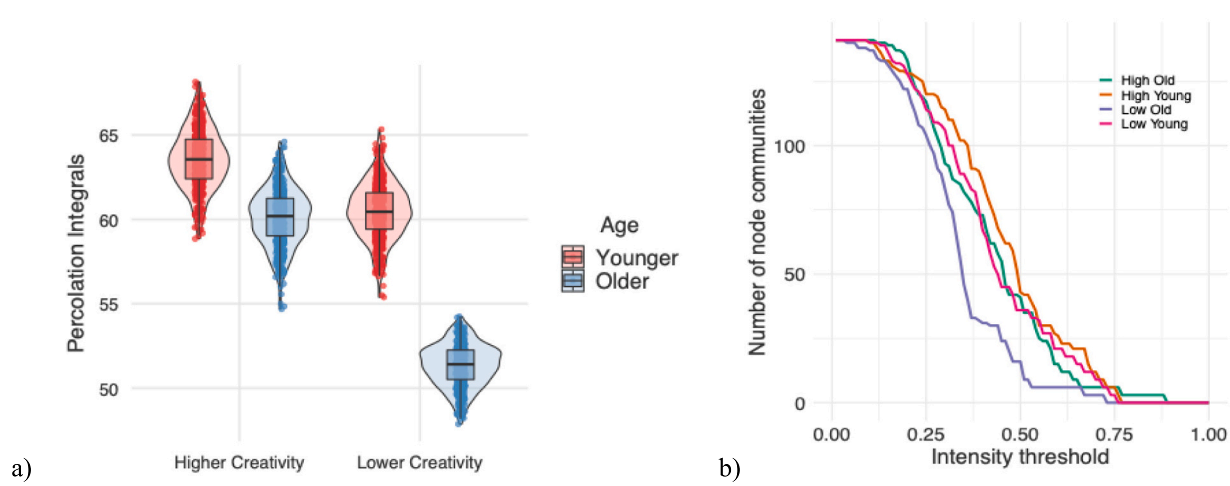

Fig. 3. Percolation analysis. Panel a): Comparison of the percolation integrals between groups. Panel b): Representation of the number of connected nodes in each network at increasing thresholds (*I*).

which to erect a creative idea.

According to the memory in creative ideation (Benedek et al., 2023) framework, older adults' decline in creative performance could be due to both a decrease in semantic memory structures flexibility and in cognitive control. According to this framework, creative performance arises from an interplay of associative, spontaneous and automatic processes with controlled, goal-directed and deliberate processes (Beaty et al., 2014; Sowden et al., 2015). A large body of research supports this theory by highlighting a robust relationship between creative ideation, associative abilities (Beaty et al., 2014; Beaty & Kenett, 2023) and cognitive control (Chrysikou, 2019; Forthmann & Nestler, 2024; Silvia, 2015). Many studies have also shown how creative performance is predicted by executive functions (Agnoli et al., 2023; Benedek et al., 2014; Zabelina et al., 2019; Zabelina & Robinson, 2010), fluid and crystallized intelligence (Frith et al., 2021; Gerwig et al., 2021), retrieval abilities (Benedek, Könen, & Neubauer, 2012; Miroshnik et al., 2023; Silvia et al., 2013) and processing speed, especially in older adults (Foos & Boone, 2008; Leon et al., 2014). This perspective highlights both the role of bottom-up (structural, automatic processes) and top-down (executive, deliberate process) processes in creative ideation, suggesting a two-stage process of divergent (i.e., recombination of concepts by creating new associations) and convergent mechanisms (i.e., executive processes aiming at monitoring the process) in creative performance. In this sense, the creative decline shown by older adults might be due to both the rigidity of the semantic memory structure and also by the decreased ability to "navigate" inside these structures and to monitor the process due to lower executive ability (Cosgrove et al., 2025; Grady, 2012a, 2012b; Paxton et al., 2008; Persson et al., 2006). In our study, we demonstrated how older adults display more rigid and less interconnected semantic memory networks are associated with a decrease in creative performance. According to the Map and Vehicle Framework (Hills & Kenett, 2022), semantic memory networks are a result of both bottom-up and top-down properties, suggesting that the difference in network properties found between groups could be caused by both structural and controlled characteristics. The specific role of each of these systems in creative abilities should be subject for future research.

4.2. Creativity in ageing: a potential protective role of semantic memory flexibility?

A critical finding of this study highlighted that differences in the semantic memory networks are associated with differences in creative performance also in older adults, an effect that resembled the results already emerged in younger adults. Our results showed that higher levels of creative performance were associated with more flexible semantic networks in both younger and older adults. Focusing on older adults, we highlight how higher creative individuals showed a higher interconnected, less segregated and less spread out network compared to the lower creative group. This effect emerged both from the structural analysis of the network and from the percolation analysis, which demonstrated a higher resiliency and flexibility of the semantic memory network of higher creative older adults in comparison to the network of lower creative older adults. Although previous literature highlighted typical semantic memory maturation dynamics in older adults (Cosgrove et al., 2021; Dubossarsky et al., 2017; Wulff et al., 2022), these results showed how these dynamics could be modulated by individuals' creative behaviour, to the extent that higher creative older adults display network properties that are similar to younger adults, even if characterized by lower creative performance. As already mentioned, even if connectivity and modularity remain more flexible in the younger group, the average shortest path length index remain stable in older creative adults in comparison to lower creative younger adults. This result might suggest that, despite the effect of age on semantic memory structures and access, higher creative individuals in old age can maintain a network that is more easily navigable (i.e., less spread out) and efficient. The maintenance of the navigation abilities in older adults can be also partly inferred by the fluency in the fluency tasks (verbal fluency and association tasks) in the higher creativity older adults, which does not show any difference in comparison with the younger groups (both high and low in creativity; see Supplementary Materials for specific analyses on the fluency scores). Although cross-sectional in nature, these results might suggest a protective role of creativity in maintaining the semantic organization's functional flexibility, interconnectivity, and accessibility.

Recently, Bieth and colleagues showed how successful problem-solving leads to a reconfiguration of individual's semantic memory network after insight (Bieth et al., 2024). Also, Kenett and Thompson-Schill (2020) showed how targeting conceptual combination – i.e., the ability to construct complex concepts from simpler constituents (Downing, 1977; Estes, 2003; Wisniewski, 1997) – could help reshape semantic memory organization and access (Kenett & Thompson-Schill, 2020). Various other studies found that conceptual nodes are not monoliths that remain stable and rigid over time, rather, they can be "stretched" and changed in shape, enabling new conceptual features to be included in the node (Chrysikou, 2006; Lai et al., 2024; Solomon & Thompson-Schill, 2017). Under this perspective, creativity could act as a reshaping force, pushing the boundaries of the conceptual space of each concept. When we engage in a creative task, we are explicitly asked to access our semantic memory and create new associations between concepts in order to generate something new and effective, stepping outside of the ordinary meaning of the concept and enriching it with contaminations coming from other concepts. In other terms, engaging in creative tasks could work as a facilitator for conceptual recombination, which in turn was demonstrated to reshape semantic organization and access to semantic memory (Kenett & Thompson-Schill, 2020). Thus, we hypothesize that by encouraging creative activities and creative thinking, we could help older adults maintain the semantic memory access and structural properties' flexibility, avoiding the typical maturation process in ageing (see for instance Colautti et al., 2023). This is in line with recent meta-analytical evidence showing a significantly positive relationship between creativity and well-being, especially when creative activities and behaviors are taken into account (Acar et al., 2021). Well-being in particular seems to be more likely to be achieved when people concretely act towards their goals and experience the outcome of their own creative activity, which suggests an important role of an active creative ageing. Again, because of the nature of the present study, we cannot rule out the possible alternative hypothesis that creativity is a symptom of healthy cognitive structure and process; however, we believe that future explorations of the relationship between creativity and ageing in the memory structures and processes could provide important suggestions and indications for healthy ageing.

Following this logic, future studies should further target the relationship between creativity and semantic organization with the aim of establishing a directionality in the association. In other terms: is a more flexible and interconnected semantic memory network that predicts higher creativity in ageing, or is it instead the engagement in more creative activities, creative behaviors and creative thinking that predicts a higher flexibility of semantic structures? Targeting these research questions is central to clarify the directionality of the relationship and potentially design training protocols that might support active and successful ageing.

4.3. Limitations and future directions

One limitation of this study is the cross-sectional nature of the design. Due to pragmatic reasons, collecting data in two different age cohorts facilitated the timing and the practicality of the research but lent itself to possible interactions with individual (e.g., generational differences) variables that might have affected the relationship. In this vein, collecting data longitudinally while maintaining the same sample (or analysing the data of national or international samples with multiple measures of semantic memory and creativity indexes across several ages) could exclude potential effects of individual variables within the relationship between creativity and semantic networks, helping to substantiate the thesis of a progressive maturation of semantic organization with ageing.

Another limitation is represented by the fact that the construction of the networks is based on group averages. Although network science often relies on group-level network estimation, future investigations should deepen the relationship between creativity and semantic networks through an individual-based network estimation. The implementation of this approach is also central due to the results of prior works that highlighted a higher heterogeneity and lower generalizability across old adults' semantic memory networks (Wulff et al., 2022), potentially because of their higher variability in life experiences and acquired knowledge (Cosgrove et al., 2023). In this sense, the TMFG filtering method used in the analysis, despite being the main filtering method used in literature for this type of research, could have filtered out some of the older adults' heterogeneity in the production (Hills, 2025; see Supplementary Material for more data on the heterogeneity of older adults' productions). In this vein, future studies could adopt an individual-based technique to help shed light on integrating both bottom-up (i.e., semantic memory structure and associative abilities) and top-down (i.e., semantic control) processes in creative ideation. A final possible limitation is related to the complexity of the creativity construct. In this study, we decided to measure creative performance through a divergent thinking task, that, even if it is considered a reliable predictor of creative performance (Runco & Acar, 2012), is also considered a statical approximation of the dynamic and multi-componential construct that is creativity (Corazza, 2016; Sternberg & Lubart, 1996). In this vein, a shift from the classical method of assessing creative performance through divergent thinking (i.e., Alternative Uses Task; Guilford, 1967) towards a more ecological way of assessing creative performance is suggested. Therefore, future research should focus on the role of semantic memory networks throughout the whole creative process (for a review, see Corazza & Agnoli, 2022), abandoning a static and one-dimensional idea of creativity.

5. Conclusion

To conclude, the present study investigated the relationship between creativity and semantic memory networks between younger and older adults. We replicated previous findings that highlight how creative people are characterized by more interconnected, more flexible and less segregated semantic memory networks (Kenett, 2025; Kenett & Faust, 2019) in both younger and older adults. Moreover, the results showed that the typical maturation of semantic memory structures of older adults (Cosgrove et al., 2021; Cosgrove et al., 2023; Dubossarsky et al., 2017; Wulff et al., 2022) is associated with a decrease in creative performance in terms of originality scores in a divergent thinking task. On the other hand, we found that higher levels of creative performance in older adults are associated with higher preservation of semantic memory network interconnection, segregation, flexibility and resiliency to attacks, suggesting a potential protective role of creativity against the maturation of the semantic memory structures and access to these structures in older adults. Thus, the present study suggests that engaging in creative behaviour during ageing could help maintain the flexible organization and access to semantic memory structure, supporting a more active and functional ageing process.

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Lorenzo Campidelli: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Umberto Domanti:** Writing – review & editing, Methodology, Investigation, Data curation. **Giulia Fusi:** Writing – review & editing, Methodology, Conceptualization. **Yoed N. Kenett:** Writing – review & editing, Supervision, Methodology, Data curation. **Sergio Agnoli:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

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Appendix A. Supplementary data

Supplementary material to this article can be found online at https://doi.org/10.1016/j.cognition.2025.106318.

Data availability

The data and code are available at https://osf.io/9cyua/?view_only=dae90b0880984e1796f5cdceccba5853.

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