Associative thinking and creative ability in older adulthood

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Abstract

Successful problem-solving and enhanced creative ability may improve physical health, cognitive well-being, and overall independence of older adults. In general, older adults who are more creative, may be better able to cope with cognitive decline and navigate everyday tasks. While previous research on creative performance in older adulthood showed age-related stability, open questions remain regarding the specific underlying cognitive basis for this invariability across the lifespan. Mediation analyses showed that intelligence measures served as underlying cognitive mechanisms for the stability of creative thinking in older age. The broader implications of these findings provide insight into the complex relationships supporting age-related preservation in creativity.

Keywords: creativity, aging, associative ability, semantics, executive control

Introduction

Individuals today have greater access to better education, healthcare, and advanced technologies to combat age-related declines, yet there are still several cognitive and physical functions that continue to deteriorate with increasing age. Older adults need to adapt to new challenges and find creative solutions for everyday problem solving (Bieth et al., 2021). Creative performance involves executive functioning and relies heavily on semantic cognition, or the ability to use knowledge acquired over the lifespan to support everyday behavioral actions (Ovando-Tellez, Benedek, et al., 2022). Moreover, creativity and aging studies have found preserved creative ability among older adults (Adnan et al., 2019). This may be related to older adults' broader semantic knowledge - a key component of creativity that facilitates the connection of weakly related concepts in memory, leading to the formation of novel ideas (Benedek et al., 2023; Kenett, 2024; Mednick, 1962). This foundational notion suggests that older adults could have a greater advantage on creative tasks given their larger vocabularies and broader knowledge base and experiences (Cosgrove et al., 2023; Park et al., 2002; Verhaeghen, 2003).

Although previous creativity and aging studies have found stability in creative performance, several studies have found differences in the aging mental lexicon that reflect less efficient semantic processing among older adults (Cosgrove et al., 2021, 2023; Hoffman, 2018; Wulff et al., 2019, 2022). Forward flow is a metric for the progression of associative thinking, which could serve as a potential mechanism for preserved creative thinking in aging. Yet, typical age-related declines in executive function may affect semantic search processes and therefore it could also be that older adults show poorer performance on forward flow measures. The present study examined age-related differences in creativity, measured through a divergent thinking task,

and associative thinking, measured by forward flow metrics. There were diverging effects of age such that creative performance remained stable for older adults, while there were age-related declines in associative abilities. Associative ability in older adulthood emulates differences in semantic processing, in that some aspects of semantic cognition, like representation, remain stable with age while other aspects that have higher executive function demands show age-related deficits. Such a similarity could further the link between creative ability and semantic processing and could have broader implications for training a more flexible semantic memory in older adults.

In the present study, age-related differences in associative thinking (operationalized through semantic relatedness) were directly compared to the stability of creative cognition in older adulthood. Through a free association task, participants provide chained associative responses that are semantically related to the previous response – these types of associations allow for a more spontaneous, free flowing train of thought that is not semantically constrained to the cue word and therefore differs from a more controlled semantic retrieval task (Gray et al., 2019). To investigate other possible underlying mechanisms, other facets of cognition, including crystallized and fluid intelligence, as well as language production ability, were related to associative thinking and creativity. This study aimed to differentiate and clarify the cognitive mechanisms underlying preserved creative thinking in aging.

Creativity and Semantic Memory

According to dual process theories, creative thinking reflects the relationship between bottom-up mechanisms of creative ideation and top-down executive functions of idea evaluation (Beaty et al., 2014; Benedek et al., 2023; Sowden et al., 2015; Volle, 2018). Creativity entails

novel ideas stemming from a recombination of current knowledge or associations between unrelated concepts (Beaty & Kenett, 2023; Benedek & Fink, 2019). According to Mednick (1962), more creative people have flat associative hierarchies – greater access to distant associates of a given concept and can therefore produce a larger number of associate responses leading to a creative solution (Benedek & Neubauer, 2013). This theory posits that individual differences in creativity stem from linking seemingly unrelated concepts into new combinations of associative concepts (Benedek et al., 2023; Kenett, 2024).

The relationship between semantic memory and creativity is further explained by the spreading activation theory of semantic memory proposed by Collins and Loftus (1975). Specifically, this theory suggests that activation of one concept spreads across related concepts in semantic memory and the intensity of this spread decays over time and connections (Kenett et al., 2017; Kumar et al., 2020). High creative individuals can more efficiently traverse their semantic memory to reach remote or weakly connected concepts in order to form novel combinations that are considered creative (Kenett, 2022; Ovando-Tellez, Kenett, et al., 2022).

Spreading activation and the semantic relationship between words has been quantified with several methodologies. One measure that relates to spreading activation is path length, which can represent the number of connections between a pair of words in semantic memory (Collins & Loftus, 1975; Siew et al., 2019). Recent studies implementing a semantic distance task found that path length more accurately predicted response time as well as strength of semantic judgements compared with semantic relatedness based on co-occurrence in text (Kenett et al., 2017; Kumar et al., 2020). Path length in semantic memory can also be extended to evaluate individual differences in creativity—with highly creative individuals having greater variability in their semantic associations which facilitates creative processing by connecting

weakly related words to form new ideas (Beaty et al., 2021; Gray et al., 2019; Kenett et al., 2019; Mednick, 1962; Merseal et al., 2023).

One way to quantitatively and empirically measure associative thought is with forward flow (Gray et al., 2019). Forward flow uses distributional semantic models (e.g., latent semantic analysis) to quantify forward progression in associative thought by measuring how far people travel in semantic space when freely associating to a cue word (e.g., *cup*; Gray et al., 2019). For example, on a chained free association task—which involves freely associating to each successive word whatever association comes to mind (e.g., *cup-coffee, coffee-tea, tea-breakfast*)—more creative individuals show higher forward flow scores than less creative individuals, even though the forward flow task does not instruct people to think creatively. In other words, participants who produce more creative ideas tend to spontaneously generate more semantically distant free associations. Moreover, forward flow measures were associated with creative achievement in real-world career entrepreneurs, visual artists, professional actors, and scientists (Gray et al., 2019; Merseal et al., 2023). Importantly, while forward flow relates to performance on divergent creative thinking tasks, such as the Alternative Uses Task (AUT), it is not related to general intelligence, which relates to cognitive control mechanisms (Beaty et al., 2021). Forward flow thus appears to capture an independent measure of semantic processing that is important for creative thinking.

Aging and Semantic Processing

Dual-process theories of creative cognition (Sowden et al., 2015), which emphasize associative and controlled processes, have parallels in semantic memory. Semantic processing involves both generating conceptual information, as well as accessing and evaluating that stored

information. The controlled semantic cognition (CSC) framework proposes an interactive relationship between the organization of semantic concepts and the semantic control mechanisms that manipulate our stored knowledge (Lambon Ralph et al., 2017). Although the CSC does not address aging directly, it aligns with patterns of age-related retention and decline that have been observed. Research has found age-related decline when there is high semantic competition, indicating that older adults are most impaired in situations with heightened semantic selection demands (Hoffman, 2018). These claims have been substantiated with patient populations. For example, individuals with semantic aphasia, which results from discrete lesions like stroke, exhibit poor performance on executive control and semantic selection tasks, but have intact semantic knowledge (Binder et al., 2009; Lambon Ralph et al., 2017). In contrast, individuals with the neurodegeneration of semantic dementia exhibit a steady degradation of conceptual knowledge compatible with a deficit in semantic representations but relatively intact performance on semantic selection tasks (Lambon Ralph et al., 2017). The double dissociation illustrated by these patient populations suggests that semantic processes and semantic representation, while interactive, are distinct aspects of semantics.

While semantic cognition is affected by age-related declines in executive function, word retrieval difficulties are less pronounced when older adults have the opportunity to utilize their rich vocabularies (Gollan & Goldrick, 2019). Specifically, during a reading aloud task, older adults can compensate for word retrieval difficulties by relying on their extensive knowledge base and enhanced vocabulary which provides them with more items from which to select (Gollan & Goldrick, 2019). Increased vocabulary knowledge can explain reduced error rates, faster reading times, and greater self-corrections for older adults. This processing is consistent with other research where increased vocabulary knowledge allows older adults to produce more

diverse and sophisticated discourse (Horton et al., 2010; Kavé & Goral, 2017; Rabaglia & Salthouse, 2011). However, after vocabulary was controlled for, age related increases in errors and fewer self-corrections remained (Gollan & Goldrick, 2019).

Although these findings suggest that vocabulary and increased knowledge can offset some age-related declines in performance (Gollan & Goldrick, 2019), language is not wholly spared from age-related impairments. Speech production abilities have been linked to three different types of executive function processing: cognitive flexibility, working memory, and inhibition. Some language production tasks, such as verbal fluency, can effectively measure the interaction of these domain-general mechanisms on linguistic output. A recent study examined three types of verbal fluency tasks – phonemic, semantic category, and task switching (Amunts et al., 2020). Better verbal fluency performance was predicted by a variety of factors, including several aspects of executive function (i.e., divided attention, inhibition, planning, working memory), as well as speed and accuracy measures (Amunts et al., 2020).

These primary predictors of verbal fluency performance—cognitive flexibility, working memory, attentional control, and inhibition—are affected by aging. The Inhibitory Deficit Theory highlights that the active, goal-directed process of inhibition is the main source of variation in cognitive performance with age (Hasher et al., 2008). In comparison to younger individuals, older adults have more difficulty ignoring distractions, down-regulating no longer relevant information, and inhibiting strong but incorrect responses. In addition to producing fewer words due to slowing processing speed, older adults also have greater difficulty switching between categories, remembering specific words they already produced, and inhibiting incorrect items. Several studies have supported this claim, where older adults consistently show poorer performance on semantic fluency tasks (Cosgrove et al., 2021; Diaz et al., 2021, 2022). More

specifically, in a study with 1,300 participants aged 16 to 95 years old, aging accounted for 23.4% of the variance in a semantic fluency production task (Tombaugh et al., 1999). In general, age-related differences are seen more broadly in semantic tasks reflecting executive functioning, while study paradigms tapping into semantic representation and lexical diversity tend to avoid age-related deficits. However, it remains unclear how semantic processing relates to creativity in aging.

Creativity and Aging

Creativity relies on executive functioning mechanisms like memory, inhibition, and attention, and these cognitive mechanisms typically decline in older adulthood (Cabeza et al., 2018; Park et al., 2002; Salthouse, 2010). Therefore, older adults may have larger deficits in executive aspects of creativity and spared ability in aspects of creativity related to creative ideation (for more details on this interaction see Benedek et al., 2023). In order to assess this relationship between associative and executive processes of creative thinking with aging, a neuroimaging study compared younger and older adults on a creative thinking task (Adnan et al., 2019). Behaviorally, younger and older adults did not differ in their creative task performance on a divergent thinking measure, potentially due to higher crystallized intelligence scores of older adults in this study. At the neural level, while older adults showed age-related declines in executive functioning behaviorally, they demonstrated stronger functional connectivity between the default network (involved in memory retrieval and idea generation) and executive control network (involved in cognitive control and idea evaluation), which may explain how their creative performance remained on par with younger counterparts.

While there are few studies explicitly linking executive function to creativity and aging, some behavioral findings further suggest age-related stability in creative cognition. On divergent thinking tasks, older adults performed equally or better than their younger counterparts (Leon et al., 2014; Palmiero et al., 2014). During idea generation, older adults can actually benefit from inhibition deficits (Hasher et al., 2008) as well as a wider knowledge base (including irrelevant information), to produce a greater number of unique and original responses (Radel et al., 2015). In convergent thinking measures that often use creative problem solving tasks, older adults outperformed younger adults when answers were previously shown as distractor items (Kim et al., 2007). Moreover, a more recent study that used a reading with distraction task and a subsequent AUT task, showed that creative performance increased when the distractions were relevant to the cue word in the divergent thinking task regardless of age (Carpenter et al., 2020). Critically, it remains possible that greater inhibitory deficits among older adults enhance their performance on the idea generation task.

Performance on the AUT has also been linked to a number of other cognitive abilities, such as episodic memory (Addis et al., 2016; Beaty & Schacter, 2018). Enhancing episodic retrieval through an episodic specificity induction can improve performance on divergent thinking tasks (Madore et al., 2015). Expanding on this initial work, Madore and colleagues (2016) examined if the benefits of this brief episodic training could generalize to creative thinking in older adults as well. In this study, half of the younger and older adult participants were trained via an episodic specificity induction paradigm while the other half were treated as the control group (Madore et al., 2016). Both younger and older adults benefitted from the episodic memory training, where AUT performance showed specificity induction effects. However, it is important to note that while older adults benefit from the episodic specificity

induction like younger adults, they still showed relatively poorer performance on both the training and control conditions compared to younger individuals. Therefore, it could be the case that older adults are relying more on semantic memory and their larger vocabularies to complete these divergent thinking tasks and to offset any age-related deficits in episodic memory (Madore et al., 2016).

Current Study

Creative thinking requires several cognitive processes, such as semantic search for idea generation and executive function for idea selection. Previous work suggests preserved creative performance in older adults, but the cognitive mechanisms underlying creative thinking in older adulthood remain unclear. In the current study, one possible mechanism of preserved creative thinking in aging—associative thinking— was explored given the relevance of associative thinking to creative performance in young adults and its reliance on semantic processes that may remain robust with age. Older and younger adults completed a free association task, and their performance was assessed via forward flow, which quantifies the trajectory of free flowing or unconstrained thoughts using distributional semantic models, thus serving as a proxy for spontaneous semantic search. To assess creative thinking, participants completed the AUT. Participants also completed a vocabulary assessment and verbal fluency measures representative of their language abilities, as well as a series completion task demonstrating fluid intelligence. These measures of broad retrieval abilities, crystallized and fluid intelligence aptitudes, have been previously linked to creative performance (Beaty et al., 2021).

Given that executive function demands may influence search strategies in the free association task, older adults may have higher forward flow values, suggestive of lowered

inhibition and attentional processing. On the other hand, the forward flow task requires participants to internally generate responses similar to a verbal fluency task, and older adults consistently score lower on semantic fluency measures despite having larger vocabularies (Cosgrove et al., 2021; Diaz et al., 2021, 2022), most likely due to age-related impairments in executive function. This prior work suggests that older adults would perform worse on a forward flow task, searching their semantic space less broadly, and generating more highly related items. Further, older adults' broader semantic memory may also lead to no age differences in the AUT, indicative of creative stability in older adulthood that has been found in previous work (Adnan et al., 2019; Leon et al., 2014; Palmiero et al., 2014). Further, it is possible that the age effects on the forward flow task and AUT performance reflect a complex relationship of the underlying mechanisms supporting associative thinking and creativity, like intelligence measures (Ichien et al., 2024).

Methods

Participants

Eighty-five younger adults (18 – 35 years, *M* = 27.38 years, SD = 4.63 years, females = 41, males = 38, non-binary = 3, and 3 individuals who preferred not to answer) and eighty-five older adults (60 – 85 years, *M* = 65.64 years, SD = 4.59 years, females = 53, males = 32) were recruited online through Prolific (https://prolific.co/). No information about race or ethnicity was collected for this online study. All participants reported no history of neurological disorder or disease and were fluent English speakers. In addition to the tasks described below, 44 of the participants in this dataset also completed a semantic relatedness judgements task (see Cosgrove et al., 2023 for more details). All participants who chose to take part in these studies provided informed consent and were paid $12/hr for their participation. Overall, the average time to

complete all the tasks (not including the relatedness judgements task) was 30 minutes for both younger and older adults. All experimental procedures were approved by the Pennsylvania State University Institutional Review Board as part of the Online Studies of Language Protocol STUDY00014804.

Data Availability Statement

All materials, analyses, and R Scripts for this project can be found here: https://osf.io/3jsr4/.

Free Association Task

Participants completed a chained free association task to measure associative ability. They were presented with a single cue word and were instructed to type the next word that comes to mind from the previous word. For this study three cue words were used to assess forward flow: pen, belt, and ladder. Recent work examining semantic distance metrics with similar lexical items found reliability across participant samples and recommended using some of the same cue words (Beaty et al., 2022). Participants were presented with a total of 19 text boxes where they needed to produce single words that were not proper nouns, consistent with past work (Beaty et al., 2021; Gray et al., 2019). While this task remained untimed, participants could not move on to the next part of the study until completing all 19 responses. Forward flow scores were then averaged across the 3 objects to obtain a single associative ability measure for each participant.

To compute forward flow, distributional semantic modeling was used, which quantifies the semantic similarity between response words by their co-occurrence in text documents. Forward flow measures the amount of change or semantic evolution within streams of thought

(Gray et al., 2019). For instance, a list of words that are all semantically related to one another would have a low forward flow value. In the current analyses, the forward flow analysis was extended by utilizing a multi-model approach (Beaty et al., 2021). This analysis included four continuous bag of words (CBOW) predict models and three count models (e.g., LSA, T7 TASA, and GloVe). While count models represent the number of times words co-occur with one another in a given text corpus, the predict models use distributed representations of context or the surrounding words in a text to predict the input word. Taken together, this multi-model approach provides a more wholistic measure of semantic relationships among words (Beaty & Johnson, 2021).

Alternative Uses Task

The Alternative Uses Task (AUT) requires participants to think of as many uses as possible for a simple object (Beaty et al., 2014; Guilford, 1967). Participants completed two trials: box and rope. For each trial, they were presented with one of the objects and asked to provide novel and unusual uses for it for one minute. Consistent with best practices in divergent thinking assessment, participants were instructed to "think creatively" (Acar et al., 2020; Said-Metwaly et al., 2020). More recently, creativity researchers automated novelty assessments by using fine-tuned large language models (LLMs). Across a number of creativity tasks, these models have shown high correlations with human ratings and have outperformed a previous assessment tool, semantic distance (DiStefano et al., 2024; Luchini et al., 2024; Organisciak et al., 2023; Raz et al., 2024). A fine-tuned LLM trained on 27k AUT ratings correlated strongly with human ratings, r = .813 (Organisciak et al., 2023), while a semantic distance scoring method, SemDis (Beaty & Johnson, 2021), had a weak correlation with human ratings, r = .12.

Moreover, automated scoring with LLMs provides an objective measure of novelty while reducing subjectivity and improving efficiency of creativity assessment. Therefore, AUT novelty scores were generated using the Open Creativity Scoring (OCS) platform (https://openscoring.du.edu) with the Ocsai 1.5 model (Organisciak et al., 2023). Scores range from 1-5, where 1 is unoriginal and 5 is very original. AUT scores for each participant were then averaged across responses from both trials.

Verbal Fluency Task

Two verbal fluency tasks were administered to measure executive functioning and language production ability. Participants completed two commonly used categorical verbal fluency tasks – *animals* and *fruits & vegetables* categories. For each of these categories, participants were presented with the category (*animals* or *fruits & vegetables*) and were given one minute to type as many members of each category that they could think of (Benton, 1968). Performance on the verbal fluency task was calculated through the number of correct responses. For the analyses, the two categories were combined since performance on the two tasks was highly correlated, $r = .77$, $p < .001$.

Vocabulary Assessments

As a measure of crystallized intelligence, participants also completed a vocabulary assessment which included two parts from the ETS Kit of Factor-Referenced Cognitive Tasks (Ekstrom & Harman, 1976): the Advanced Vocabulary Test II (18 items, 4 minutes) and the Extended Range Vocabulary Test (24 items, 6 minutes). Both tests included multiple choice questions that presented a target word with four to five answer choices. Participants were asked

to choose the word that best described the target word. Performance on these tasks was measured as the sum of overall accurate responses and these tasks were combined for analyses, $r = .57$, $p < .001$.

Fluid Intelligence Assessment

Fluid intelligence was assessed through the Culture Fair Intelligence Test (CFIT; Cattell & Cattell, 1960) to assess nonverbal intelligence. More specifically, in this task participants were presented with a series completion task (Cattell & Cattell, 1960), where they needed to detect the pattern of changing images to accurately determine the subsequent image. There was a total of 13 items and the assessment was timed for 3 minutes.

Statistical Analyses

We ran independent sample *t*-test analyses to examine whether the individual-based associative thinking measures of forward flow, AUT creative performance, language production ability (verbal fluency), crystallized intelligence (vocabulary) and fluid intelligence (Cattell) differed between younger and older adults. Next, collapsing across age groups, individual-based associative thinking and creativity measures were compared to verbal fluency performance, vocabulary knowledge, and fluid intelligence via separate linear regression analyses. In addition, we ran mediation analyses to assess whether including verbal fluency, vocabulary, or fluid intelligence affected the relationship between age and forward flow or age and AUT performance. The significance of this indirect effect was tested using bootstrapping procedures. Standardized indirect effects were computed for each of 500 bootstrapped samples, and the 95% confidence interval was computed by determining the indirect effects at the 2.5th and 97.5th

percentiles. Before running any linear regressions or mediation analyses, the data was standardized through z-score normalization to ensure proper comparison between tasks.

A few missing data points, less than 5% of the task data in our participant sample, were imputed using the mice package in R (van Buuren & Groothuis-Oudshoorn, 2011). The mice package imputes missing data through chained equations with plausible values calculated through stochastic regression imputation with the complementary variables in the dataset. This multiple imputation method generates several imputed datasets to account for any uncertainty introduced by imputed missing values and therefore handles the variance in the data better than mean replacement methods.

Additionally, we applied the Z-score method to detect outliers in task performance for all participants. The Z-scoring standardizes the data by subtracting the mean and dividing by the standard deviation. A threshold of $|Z| > 2.5$ was used to identify outliers. Data points with Z-scores beyond this threshold were considered outliers. Participants were then removed from the analyses if their responses on any task reflected poor performance.

Results

Age Differences in Creativity, Associative Abilities, and Intelligence Facets

A critical aspect of this study aimed to tease apart the underlying mechanisms supporting creative performance and associative thinking and how these undergo age-related differences. As expected, the results show varying age-related differences in creative performance and associative abilities between the two age groups, with age-related stability in creative performance and age-related decline in associative abilities (see **Figure 1**).

[Add Figure 1]

Interestingly, results from the associative thinking task exhibited significant age-related differences. Older adults showed lower performance on the forward flow task. Independent sample *t*-tests showed that younger and older adults significantly differed on the dynamic forward flow measure of semantic distance such that forward flow values were lower for older adults, $t(168) = -3.8$, $p = < .001$, d = -0.58. For an example of younger and older adult responses to the cue word "belt", see **Figure 2**. Overall, there were no significant age-related differences in creativity as measured by the AUT, $t(168) = -1.68$, $p = .09$, d = -0.26. Consistent with previous findings , creative performance showed age-related stability.

[Add Figure 2]

Next, age differences were examined in fluid, crystallized, and broad retrieval abilities. Summary statistics for these measures including mean and standard deviation scores are reported in **Table 1** below. As expected (Cosgrove et al., 2023), vocabulary knowledge was significantly greater for older adults, $t(168) = 5.82$, $p < .001$, d = 0.89. In addition, an independent sample *t*-tests revealed that fluid intelligence scores, measured from the Culture Fair Intelligence Test (CFIT; Cattell & Cattell, 1960), were lower for older adults, $t(168) = -5.94$, $p < .001$, d = -0.91. There were also significant age differences in language production, where older adults' total number of verbal fluency responses were less than younger adults, $t(168) = -2.58$, $p = .01$, d = -0.4.

[Add Table 1]

Creativity, Associative Thinking, and Intelligence Facets

First, the effect of associative thinking on creative performance was examined. There was a significant positive correlation between the forward flow metrics and AUT measures across all participants, $F(1,168) = 4.64$, $p = .03$, r = .16, indicating a statistically significant relationship

between forward flow and AUT creative performance. Then, the relationship between fluid intelligence measures and creativity were examined regardless of age. Collapsing across age groups, the intelligence facets – verbal fluency, fluid intelligence, and vocabulary knowledge – were regressed on AUT creativity scores via separate linear regressions. Vocabulary knowledge was significantly related to the AUT performance, $F(1,168) = 9.56$, $p = .002$, r = 0.21. This relationship shows that overall vocabulary knowledge was positively related to an individual's creative ability. In addition, fluid intelligence scores were significantly positively related to the AUT scores, $F(1,168) = 21.32$, $p < .001$, r = 0.32. Verbal fluency, however, was not significantly correlated with AUT creativity scores $F(1,168) = 3.19$, $p = .07$, r = 0.15.

The cognitive assessments were also compared to associative abilities as measured by forward flow. Collapsed across age-groups, vocabulary was not significantly related to associative abilities, $F(1,168) = 1.63$, $p = .2$, r = -0.09. On the other hand, fluid intelligence measures correlated with associative abilities $F(1,168) = 11.97$, $p < .001$, r = 0.28. Verbal fluency scores were also significantly related to associative abilities $F(1,168) = 10.33$, $p = .001$, r = 0.24.

Although these age-related differences in vocabulary knowledge, language production, and fluid intelligence measures largely replicate prior cognitive aging research (Diaz et al., 2021; Park et al., 2002; Salthouse, 2010; Verhaeghen, 2003), it is possible these intelligence factors mediate the age-creativity or age-forward flow relationships. In order to explore these potential relationships further, mediation analyses were conducted.

Vocabulary had a significant mediating effect on the relationship between AUT performance and age. The mediation analysis revealed a significant indirect effect of age on AUT scores through vocabulary knowledge (indirect effect = 0.14, 95% CI [0.07, 0.24], *p*

< .001), indicating that the relationship between age and creative ability was partially mediated by vocabulary knowledge. The effect of age on AUT performance was also partially mediated by fluid intelligence measures. The mediation analysis revealed a significant negative indirect effect of age on AUT scores through fluid intelligence (indirect effect = -0.14, 95% CI [-0.22, -0.07], p < .001). However, verbal fluency scores did not mediate the relationship between age and AUT performance, (indirect effect = -0.02, 95% CI [-0.07, 0.01], p = .2).

As with creativity, we were also interested in potential mediators of the relationship between age and associative thinking (as measured by forward flow).The mediation analysis revealed a non-significant indirect effect of age on forward flow scores through vocabulary knowledge (indirect effect = 0.01, 95% CI [-0.05, 0.08], p = .71), indicating that the relationship between age and associative thinking was not partially mediated by vocabulary knowledge. Fluid intelligence also did not mediate the effect of age on forward flow metrics, indirect effect = -0.07, 95% CI [-0.14, 0], p = .07). Finally, language production ability was a significant factor in the effect of age on forward flow, indirect effect = -0.04, 95% CI [-0.08, -0.01], p = .004). The implications of these mediation results show that other cognitive measures, like crystallized and fluid intelligence, significantly contribute to the relationship between creativity and age, while language fluency affects age-related differences in associative abilities.

Discussion

The associative theory of creativity (Beaty & Kenett, 2023; Mednick, 1962) highlights the importance of semantic memory structure in facilitating creative idea generation. Critically, this theory has been supported through computational network science research that revealed structural differences between the semantic memory network of high and low creative

individuals (Kenett & Faust, 2019). High creative individuals have been shown to have organizational differences in their semantic memory structure which facilitates the spread of activation between concepts in semantic memory, mediating connections between distant associations (Kenett et al., 2014; Kenett, 2024). Such individual differences in the size and structure of semantic memory among creative individuals suggests that semantic memory may also change with age and the ability to efficiently traverse one's semantic memory network given these age-related differences may in turn influence creative ability.

The present study aimed to examine the relationship between semantic associative ability, creative performance, and aging. The results showed that while creative ability remained stable across younger and older adults, older adults showed lower performance in associative abilities as measured by a forward flow analysis compared to younger individuals. Moreover, the relationship between age and creative ability was mediated by both vocabulary and fluid intelligence, highlighting two potential mechanisms underlying age-related preservation in creative ability. This work and the present study results further highlight the importance of differentiating the mechanisms underlying creative cognition, especially with regards to aging populations.

Creativity, Associative Ability, and Aging

The present study once again demonstrates that the underlying mechanisms of creative thinking are differentially affected in aging (Adnan et al., 2019; Carpenter et al., 2020; Fusi et al., 2021). Performance on the AUT showed age-related stability between the two groups as this task taps into more representational aspects of semantic memory. Consistent with the aging literature (Cosgrove et al., 2023; Park et al., 2002; Salthouse, 2010) older adults had greater

crystallized intelligence scores (i.e., vocabulary knowledge), lower fluid intelligence, and lower verbal fluency scores compared to younger adults. Critically, vocabulary knowledge and fluid intelligence significantly mediated the relationship between creative performance and age. It is possible that these two components of creativity, semantic knowledge and fluid intelligence, share a combined influence on older adults' performance in that they benefit from larger vocabularies, but experience a disadvantage due to their declines in fluid intelligence. Recent work has shown that fluid and crystalized intelligence measures have independently contributed to creative metaphor comprehension in older adults (Ichien et al., 2024). While the results from the AUT and cognitive measures are fairly consistent with the broader creativity and aging literature (Adnan et al., 2019; Palmiero et al., 2014; Verhaeghen, 2003), the critical aspect of this study focuses on the age-related differences in forward flow. What can forward flow tell us about semantic cognition and creativity in aging?

Older adults had significantly lower forward flow scores compared to younger adults, indicating that their semantic search strategies are more constrained and less flexible. Forward flow reflects a mechanism of creative thinking, in how individuals spontaneously navigate through semantic space, not necessarily creativity itself (Kenett et al., 2020). Forward flow is a measure of the semantic distance based on word co-occurrence that quantifies how much a current thought semantically diverges from the previous thought in a free association task (Gray et al., 2019). Beaty and colleagues (2021) have previously found that forward flow and intelligence measures separately predict creativity, and consistent with this both forward flow and intelligence were correlated with AUT performance in the current study. Yet it is possible that this relationship changes with increased age. Although crystallized intelligence as represented by overall vocabulary knowledge was not related to forward flow, verbal fluency

performance was, with older adults showing lower performance on both verbal fluency and forward flow, compared to younger adults assessed through independent t-tests. One of the consequences of having a larger vocabulary in older adulthood is that there are many more representations to search through and select from which could have negative consequences during timed tasks such as verbal fluency (Cosgrove et al., 2023; Ramscar et al., 2017).

These findings relate to previous creative cognition models where creativity occurs in two stages: idea generation stemming from knowledge in long-term memory and the subsequent evaluation of these ideas (Adnan et al., 2019; Benedek et al., 2023). It is possible that age-related increases in vocabulary may be related to enhanced idea generation (e.g., AUT task), while age-related declines in semantic selection – or executive functioning more generally – relate to issues in this second stage of idea selection. Older adults require greater semantic control to retrieve these weak semantic connections (or more divergent responses) facilitating conceptual recombination in creativity (Adnan et al., 2019). Furthermore, such age-related vocabulary increases may impact meta-cognition involved in idea evaluation (Kenett, 2022; Lebuda & Benedek, 2023; Sidi et al., 2020).

Additionally, the diverging effects of forward flow and the AUT in aging could speak to the nature of the cognitive processes that the two tasks tap into. These results may underscore how aging further differentiates the underlying cognitive mechanisms supporting the free association and creativity tasks. Forward flow utilizes spontaneous associative recall from semantic memory which could be more affected by age-related deficits in top-down cognitive control strategies. The AUT utilizes prior knowledge to produce unique responses to a specific item, in this task older adults can tap into their vast semantic store, compensate for age-related declines in intelligence, and thus diminish any age differences.

The diverging aging results between the AUT and forward flow could also stem from differences in older adults' strategy use – they can effectively employ strategies (when instructed to do so), but often do not when left to their own devices. The AUT specifically asks participants to "think creatively" and focuses on novelty. Previous work has shown that providing older adults with explicit strategies improves performance on verbal working memory tasks (Hering et al., 2018). This effect could generalize to other aspects of semantic memory like concept representation and idea generation which benefits AUT performance. Alternatively, the forward flow instructions ask participants to produce a chain of related words, but do not provide an explicit strategy or guide to be creative. More so, the forward flow paradigm is based on a free association task where performance can serve as a window into how someone searches semantic space. Forward flow analyses therefore may better reflect spontaneous semantic search processes of younger and older adults. More specifically, this task reflects whether an individual's ability to search their semantic memory is efficient, divergent, or redundant. Previous studies have shown that the structure of older adults' semantic memory tend to be less connected, less efficient and less robust (Cosgrove et al., 2021; Dubossarsky et al., 2017; Wulff et al., 2019). Given a less efficient and less interconnected semantic memory organization, older adults may require greater executive function to search for semantically related words.

It could also be the case that the different semantic associations produced by younger and older adults reflect competitive and cooperative effects of semantic representation respectively. Previous work examining the effects of activation among semantic neighbors found that there were facilitative effects of semantic neighbors for lexical retrieval when these neighbors were weakly activated and inhibitory effects when these neighbors were strongly activated (Chen & Mirman, 2012). Our older adults could have weaker activations among competing semantic

information leading to the selection of more closely related words. Younger adults, likely endure more inhibitory effects since their activation among other semantic neighbors remains stronger, causing more competition for closely related words. This semantic interference could influence their response choices so that they produce more semantically distant associations.

Limitations and Future Directions

Online data collection enhances the ecological validity of cognitive aging research by providing researchers with the opportunity to include a broader sample of participants. However, there may be cohort effects when it comes to the practical limitations of online studies for older adults. That is, older adults may find an online study paradigm to be more taxing due to possible slower typing speeds during timed tasks. Typically, older adults who participate in online studies are technologically savvy and confident enough to engage in online experiments. However, these are also common characteristics of older adults who participate in in-person experiments. In fact, a recent study found similar performance levels among older adults who completed the same cognitive computer tasks administered either at-home and in laboratory settings (Cyr et al., 2021). Though online data collection poses some limitations, we find our more standard behavioral measures such as semantic verbal fluency, vocabulary, and fluid intelligence performance to be representative of typical, in-person cognitive aging research (see Diaz et al., 2021 and Park et al., 2002).

Future work should continue to study cognitive correlates of creative thinking in aging. In a recent article by Yang, Kandasamy, and Hasher (2022), the authors note that a multitude of cognitive and environmental factors including inhibition deficits, cognitive reserve, mind wandering, and artistic hobbies that likely mediate the relationship between creativity and aging.

While creativity research has tended to focus on younger adults, these findings could be used as the foundation of future training studies that could implement creative paradigms to increase the flexibility of semantic memory in older adulthood. As shown in network science research, greater flexibility in semantic memory structure related to more efficient processing of semantic memory (Kenett et al., 2014; Kenett & Faust, 2019), and older adults show diminished flexibility in semantic memory (Cosgrove et al., 2021, 2023). Training strategies that increase flexibility in the semantic memory structure of older adults could aid in more successful semantic selection abilities.

Furthermore, network science provides a computation approach to simultaneously mapping semantic memory organization and processing. Though semantic memory networks calculated from free association data have previously been linked to creative performance (see Kenett et al., 2014, 2018 for more details), these studies require group-based analyses that aggregate across participant responses and cannot account for individual differences in semantic distance measures. Future network science work should aim to create a method for assessing associative thinking from free association data at the individual level.

Conclusions

Similar to semantic cognition, creative associative thinking entails the connection of weakly related concepts (Beaty & Kenett, 2023; Mednick, 1962) and involves top-down cognitive control strategies that traverse semantic memory and retrieve unique combinations (Beaty et al., 2014; Beaty & Kenett, 2023; Benedek et al., 2023). These findings suggest that highly creative individuals have a more flexible semantic memory allowing for efficient search and connection of remotely related concepts (Kenett, 2022; Ovando-Tellez et al., 2023). Studies

have emphasized the importance of assessing individual differences in memory retrieval and creative processing in older adulthood (Kenett & Faust, 2019; Kenett, 2024; Wulff et al., 2019). The current study's results suggest that while there were age-related differences in associative abilities, this likely speaks to variability in semantic search strategies, semantic memory flexibility, and the distinct underlying cognitive mechanisms that influence task demands. In contrast, AUT performance relies heavily on prior knowledge and semantic representation to lessen any age effects. Overall, these findings suggest that while certain aspects of semantic cognition and creativity remain stable across adulthood, like idea generation or reframing conceptual information, other mechanisms reflecting spontaneous semantic search strategies showed age-related deficits. More so, these higher level cognitive abilities are supported by other mechanisms – age-related stability in creative performance is mediated by crystallized and fluid intelligence, and language fluency affects age differences in associative ability. These conclusions have important implications for the field of creativity, aging, and semantic memory.

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Disclosure Statement

The authors report there are no competing interests to declare.

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Table 1. Summary statistics for creativity measures of forward flow (range of 0-1), and AUT (range of 1-5), as well as verbal fluency, vocabulary performance, and fluid intelligence scores for younger (YA) and older adults (OA).

Independent *t*-tests examining age effects of cognitive measures	**OA Mean (SD)**	**YA Mean (SD)**	***t*-values**	***p*-values**	**Cohen's d**
Forward Flow	0.79 (0.03)	0.81 (0.03)	-3.8	< .001	-0.58
AUT Creativity	1.78 (0.23)	1.85 (0.27)	-1.68	.09	-0.26
Verbal Fluency Total	29.49 (10.36)	33.91 (11.92)	-2.58	.01	-0.4
Vocabulary Total	28.87 (6.1)	23.38 (6.2)	5.82	< .001	0.89
Fluid Intelligence	6.53 (1.89)	8.16 (1.69)	-5.94	< .001	-0.91

Figure 1. Significant age-related differences in the forward flow metrics between younger adults and older adults (Left). No differences among age groups for the AUT creativity measures quantified by human ratings (Right).

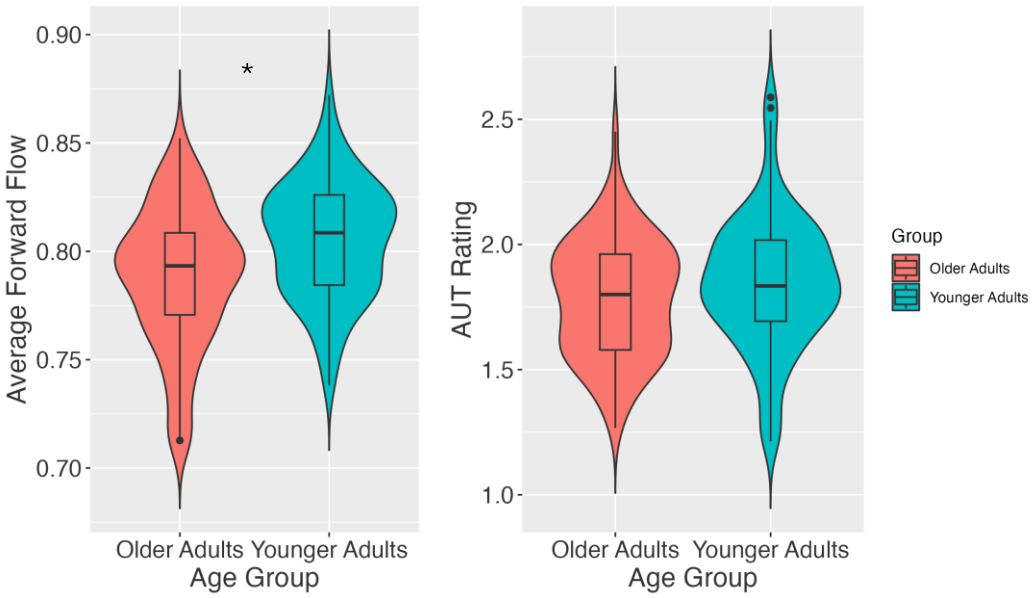

Figure 2. Example of forward flow metrics for one younger adult and one older adult in response to the cue word "belt". Forward flow mean value for each participant's response reflects the averaged multi-model approach described in (Beaty & Johnson, 2021).