Domain general processes moderate age-related performance differences on the mnemonic similarity task

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ABSTRACT

Several prominent domain general theories (e.g., processing speed and inhibitory function) have been developed to explain cognitive changes associated with aging. A bias to “pattern complete” in aging has also been suggested to account for age-related changes that are specific to episodic memory. The current experiments test whether domain-general processes of cognitive aging moderate the bias to pattern complete. The study phase of the mnemonic similarity task, a memory task with old, new, and similar trials at recognition, was manipulated to assess the contribution of processing speed (Experiment 1 – different encoding times) and inhibitory function (Experiment 2 – item-level directed forgetting) to the age-related bias to pattern complete in a sample of 100 healthy younger and older adults. Both experiments exhibited significant interactions between age group and encoding manipulation, replicating a bias to pattern complete in aging, and indicating that processing speed and inhibitory function moderate this effect. Age-related differences in performance on the mnemonic similarity task are moderated by experimental manipulations of domain general processes that also decline with age, providing evidence for conditions that can ameliorate and explain performance decrements on the mnemonic similarity task in older adults.

Keywords: Mnemonic Similarity Task, Cognition, Memory, Inhibition

1-Introduction

Changes in cognition occur as individuals age. Although not all cognitive processes show age-related impairment, it is common to observe declines in perception, attention, processing speed, episodic memory, and working memory (Craik & Salthouse, 2008). Several prominent theories have been put forth to account for such age-related alterations in cognition, including a change in processing speed (e.g., Salthouse, 1996a, 1996b) and impairments in inhibitory processes (e.g., Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Zacks, Hasher, & Li, 2000). Notably, such theories are domain-general explanations of cognitive aging in that a single factor explains a wide variety of cognitive changes that are associated with aging.

More specifically, domain-general theories of cognitive aging suggest that a primary reason for poorer memory performance in older adults (OAs) is a reduction in the fidelity of the encoded memory representation. For example, the processing speed theory suggests that OAs either need more time to create a robust representation, or are unable to build the same strength of representation due to degradation of previously processed information (Salthouse, 1996b). Similarly, the inhibition deficit suggests that OAs are less able to maintain a clean mental workspace and, therefore, are more likely to encode (or be distracted by) irrelevant information, reducing the quality of goal relevant representations (Campbell, Trelle, & Hasher, 2014; Lustig et al., 2007; Zacks et al., 2000).

The hippocampus, a medial temporal lobe brain structure, supports episodic memory by creating an orthogonalized neural code even when the to-be-encoded representation is similar to one encountered in the past. The hippocampus is also thought to aid in the completion of a previously encountered representation despite incomplete information (Bakker, Kirwan, Miller,

& Stark, 2008; Berron et al., 2016; Knierim & Neunuebel, 2016; Kyle, Stokes, Lieberman, Hassan, & Ekstrom, 2015; Leal & Yassa, 2018; O'Reilly, Bhattacharyya, Howard, & Ketz, 2011; Yassa & Stark, 2011a). The ability to create a novel code in the face of similarity is referred to as pattern separation, while the ability to generalize degraded or partial information into a previously stored code is referred to as pattern completion (Bakker et al., 2008; Berron et al., 2016; Knierim & Neunuebel, 2016; Kyle et al., 2015; Leal & Yassa, 2018; Yassa & Stark, 2011a). Recently, the notion has been put forth that age-related episodic memory deficits reflect a bias to pattern complete (for review see Leal & Yassa, 2015). While it is not possible to directly measure hippocampal separation and completion processes in human participants, research in both humans and animals suggests that age-related discrimination deficits reflect anatomical and functional changes within the hippocampus, which underlie a bias towards pattern completion as compared to separation (Holden & Gilbert, 2012; Kirwan & Stark, 2007; Leal & Yassa, 2015; Stark, Stevenson, Wu, Rutledge, & Stark, 2015; Stark, Yassa, Lacy, & Stark, 2014; Toner, Pirogovsky, Kirwan, & Gilbert, 2009; Yassa, Mattfeld, Stark, & Stark, 2011; Yassa & Stark, 2011b).

The bias to pattern complete (i.e., a greater propensity by older adults to endorse similar objects as previously seen) has typically been tested using the mnemonic similarity task, a task that manipulates the similarity between a previously encoded episode and an episode encountered during a memory test (e.g., Kirwan & Stark, 2007; Motley & Kirwan, 2012). As similarity between the two episodes increases, processes that support pattern separation are thought to be engaged to a greater extent. The mnemonic similarity task has assessed memory performance across several types of to-be-encoded items, including objects (Stark, Yassa, Lacy, & Stark, 2013), scenes (Stark & Stark, 2017), and spatial relationships (Reagh et al., 2014; Stark,

Yassa, & Stark, 2010), as well as under conditions testing conceptual memory using both pictures (Pidgeon & Morcom, 2014) and words (Ly, Murray, & Yassa, 2013). Further, the task itself has been manipulated to assess the effects of encoding intentionality and time at decision making on performance (Stark et al., 2015). Consistently, an age related bias to pattern complete has been shown, suggesting that pattern separation and completion processes are fundamental memory functions, and that age-related alteration of these processes underlies episodic memory changes, regardless of the type of processing or modality.

Despite the consistency in these findings, the current experiments assessed the extent to which age-related performance differences on the mnemonic similarity task may be moderated by domain-general processes that also differ as a function of age. Specifically, in Experiment 1, encoding time was manipulated to assess the role of processing speed on the bias to pattern complete. In Experiment 2, a directed forgetting paradigm was used to assess the role of inhibition on the bias to pattern complete. We hypothesized that performance on the mnemonic similarity test would be altered in both OAs and YAs in Experiment 1, but only in YAs in Experiment 2. The extent to which memory performance may be modified in either group would provide evidence that domain general processes not only contribute to age-related memory differences (Lustig et al., 2007; Salthouse, 1996a; Zacks et al., 2000), but that they specifically account for mnemonic processes (i.e., pattern separation and completion) thought to be measured by the mnemonic similarity task.

2-General Methods

2.1-Participants

Each experiment employed a within subjects design and included 50 subjects (25 YAs and 25 OAs). Young adults ranged in age from 18 – 27 years and were recruited from the

Psychology and Neuroscience participant pool at UNC Chapel Hill or through flyers displayed throughout the local community. OAs ranged in age from 60–86 years and were recruited from the local community with flyers and emails. All participants were screened to be free of a history of neurological and psychiatric disorders and required to score ≥ 27 on the Mini Mental State Exam to be included in the study (Folstein, Folstein, & McHugh, 1975). Participants provided informed consent. The UNC Chapel Hill Institutional Review Board approved the study. All participants received course credit or compensation of \$10/hour for their time. Participants were also given several cognitive tests prior to the experiment to obtain standardized measures of cognition, including digit span forward/backward (Wechsler, 2008), Trails A/B, and conditions 1-3 of the color-word interference subtest of the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001).

2.2-Stimuli

The mnemonic similarity task was modeled after Motley & Kirwan (2012) where degree of rotation between a studied picture and a picture presented at recognition was used as the measure of similarity. Images of common objects were obtained from the Amsterdam Library of Object Images (Geusebroek, Burghouts, & Smeulders, 2005) of which 288 images were selected for the current experiments. In keeping with the original study, lure similarity was operationalized according to four degrees of rotation from the original presentation (15°, 25°, 35°, and 55°). An angle was chosen at random for each object presented at study, and this angle was used as 0° rotation at test. The direction and degree of rotation from the original presentation was pseudo-randomly chosen with the constraint that approximately equal number of stimuli were present in each of the rotation categories. Each subject was presented with a randomly generated list of objects for study and test.

2.3-Procedure

Before the encoding session, participants were informed about the memory task, including the fact that they would be tested with exact repeats of previously encountered items (to which they should indicate “old”), new items (to which they should indicate “new”), and rotated items (i.e., lure trials – to which they should indicate “rotated”). Participants were given a practice session of both the study and test portions of the memory task before beginning the experiment. During encoding, participants made “toy” or “not toy” judgments.

At study, participants were shown a series of 192 common objects, one at a time presented in the center of a computer screen, for 2.5 sec each with a 0.5 sec inter-stimulus interval (unless otherwise noted). At test, participants were presented with 288 objects, 96 repeated, 96 rotated lures, and 96 novel foils. Half of the repeats and lures were taken from the within-subjects manipulations described in each experiment, leaving approximately 12 trials for each degree of rotation. Stimuli were presented with E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). To assess whether performance on the mnemonic similarity test was influenced by age related differences in the ability to discern rotation, all participants were given a rotation test (see supplemental materials). Performance on the mnemonic similarity task was measured using a mnemonic similarity index (MSI) which was calculated as one minus the probability of indicating “old” for repeat trials and for each degree of rotation (Stark et al., 2013).

3-Experiment 1: Processing speed and the completion bias

According to the limited time mechanism of the processing speed theory, processing speed declines with age such that more time is needed by OAs to complete the same amount of processing as YAs (Salthouse, 1996a). To assess whether or not memory is impacted by the rate of presentation at encoding, and whether this systematically affects performance on lure trials,

two different rates of presentation were employed as a within-subjects manipulation for both age groups. For YAs, half of the stimuli were presented at a rate of 1.25 sec and half were presented at a rate of 2.5 sec. For OAs, half of the stimuli were presented at a rate of 2.5 sec and half were presented at a rate of 5 sec. For both groups, the rate of presentation changed every 8 objects. Participants were also presented with a screen during the regular fixation period indicating whether the next 8 objects would be presented at the “fast” or “slow” rate.

Critically, this experiment matches the speed at which the two age groups are presented information (2.5sec–Standard, i.e., a typical rate used in the literature), and manipulates the rate of presentation such that YAs receive a faster than standard pace (1.25sec–Non-Standard) and OAs receive a slower than standard pace (5sec–Non-Standard). Thus, the current experiment includes the necessary conditions to test for the typically observed bias to pattern complete, the relative improvement or decrement in performance as a function of encoding time, and the extent to which the two age groups performance is mirrored under the manipulated encoding time conditions. We conducted the analysis as standard and non-standard presentation rates, as opposed to “fast” and “slow”, in order to clearly test our set of hypotheses that: OAs will exhibit a typically seen deficit in the standard condition, OAs will exhibit improved performance when given more encoding time, and that, YAs will exhibit reduced performance when given less encoding time.

3.1-Experiment 1: Results

3.1.1-Participants

OAs were significantly more educated, $t(48)=-9.47, p<.001$, as compared to YAs. OAs were also slower to perform Trails A, $t(48)=-4.17, p<.001$, Trails B, $t(48)=-2.80, p=.007$, color naming time, $t(48)=-4.01, p<.001$, word reading time, $t(48)=-2.19, p=.033$, and color-word

interference time, $t(48)=-5.21, p<.001$. As a more direct measure of inhibition, we subtracted the color naming time from the color-word interference time and this measure was also significantly different between OAs and YAs, $t(48)=-4.14, p<.001$, suggesting that OAs in our sample had reduced processing speed and reduced inhibitory processes. There were no other group differences (See Table 1).

----- Insert Table 1 about here -----

3.1.2-Mnemonic similarity index

To ensure the MSI was appropriate for this data set, we tested whether there were age-differences in rates of responding new to old, lure, or new trials and found no significant differences (see supplemental materials). The MSI was the dependent variable in a 2(Group: YA vs. OA) x 2(rate of presentation: standard (2.5sec) vs. non-standard (1.25 or 5sec)) x 5(degree of rotation: repeat-55°) repeated-measures ANOVA. Rate of presentation and degree of rotation were within-subjects factor and group was a between-subjects factor (see Figure 1). Results revealed a significant main effect of degree of rotation, $F(4,192)=121.93, p<.001, \eta_p^2=.72$, such that performance improved significantly across the increasing degrees of rotation. There was a significant main effect of group, $F(1,48)=6.74, p=.013, \eta_p^2=.12$, indicating that YAs performed better than OAs overall, as well as a significant three-way interaction between degree of rotation, rate of presentation, and group, $F(4,192)=4.06, p=.004, \eta_p^2=.08$. There were no other significant effects $ps>.151$.

To probe the three-way interaction, we conducted linear contrasts across degree of rotation. In the standard rate of presentation, we found a significant difference in the linear trend across degree of rotation between YAs and OAs, $F(1,48)=10.33, p=.002, \eta_p^2=.18$, where OAs exhibited a significantly less steep slope, as compared to YAs. In the non-standard rate of

presentation, however, YAs and OAs exhibited similar slopes across degree of rotation, $F(1,48)=2.56, p=.117, \eta_p^2=.05$, providing evidence that reducing encoding time in YAs and increasing encoding time in OAs served to equate performance. Further, both groups exhibited better performance as compared to themselves when given more time at encoding (YAs standard>non-standard, $F(1,24)=4.88, p=.037, \eta_p^2=.17$; OAs non-standard>standard, $F(1,24)=13.05, p=.001, \eta_p^2=.35$) and this benefit in performance was similar regardless of age, $F(1,48)=0.10, p=.748, \eta_p^2=.002$.

----- Insert Figure 1 about here -----

3.2-Discussion

The results of this experiment support the hypothesis that age-related processing speed deficits contribute to the bias to pattern complete in aging. First, in the standard rate of presentation OAs exhibit the typical age related deficit in performance on the mnemonic similarity task, showing a less rapid increase in performance across degree of rotation. Second, the results revealed that both OAs' and YAs' ability to recognize lures was significantly impacted by the amount of time given to study a stimulus. Both groups performed significantly better across degrees of rotation when they were given more time to encode the stimulus and performance was equated between OAs and YAs in the non-standard rate of presentation. Finally, while age group differences were observed on the rotation test, controlling for performance on the rotation test did not change the pattern of significant results across all analyses (see supplemental materials). Thus, both a manipulation of encoding time, and the relationship between performance and measures of processing speed, provide convergent evidence that processing speed plays a critical role in pattern separation and completion processes as measured by the mnemonic similarity task.

4-Experiment 2: Inhibition deficit and the completion bias

To test whether inhibitory processes contribute to performance on the mnemonic similarity task, the current experiment adopted methods from Zacks et al. (1996); however, pictures, instead of words, were used as stimuli. Zacks et al. (1996) used an item-level directed forgetting paradigm and found that words in the to-be-forgotten condition were recognized to the same extent for both OAs and YAs, while items in the to-be-remembered condition were recognized significantly more by YAs. The difference in performance as a function of directed forgetting in YAs, as compared to OAs, is interpreted as evidence that OAs have altered inhibitory processes; namely a reduced ability to suppress processing of no longer relevant information. A reduced ability to inhibit irrelevant information could lead to holding onto previous trial information too long, reducing the fidelity of the to-be-encoded information, and could potentially account for a bias to pattern complete seen in aging.

We hypothesized that the pattern of performance across all trial types would be similar for OAs in both the to-be-remembered and to-be-forgotten conditions, as well as for YAs in the to-be-forgotten condition. We additionally hypothesized that YAs in the to-be-remembered condition would show better performance relative to OAs. Prior research using an item-level directed forgetting paradigm has shown that the difference between recognition rates is greatly reduced when using pictures (Hauswald & Kissler, 2008). As such, employing picture stimuli in the current study would likely reduce the overall effect on directed forgetting for the recognition of repeats, while allowing an effect to remain on the finer grain discrimination involved in the lure trials.

For the current experiment, participants were told that, a letter would appear on the screen (i.e., R or F) after each object. If they saw an “R” or “F” they were to remember or forget

that object for the later memory test. They were also told that forgetting the to-be-forgotten objects would aid in their memory for the to-be-remembered objects. The letter was displayed for 1.5 sec after the presentation of the object and was followed by a 0.5 sec inter-stimulus interval. The directed forgetting manipulation was presented randomly but split evenly between the studied stimuli.

4.1-Results

4.1.1-Participants

One YA was removed from the analysis due to chance level performance and replaced with another YA participant. The OA participants were significantly more educated, $t(48)=-11.02, p<.001$. Again, the OAs were also slower to perform Trails A, $t(48)=-5.12, p<.001$, Trails B, $t(48)=-4.09, p<.001$, color naming time, $t(48)=-3.89, p<.001$, word reading time, $t(48)=-4.52, p<.001$, and color-word interference time, $t(48)=-5.70, p<.001$. We again subtracted the color naming time from the color-word interference time. This measure was also significantly different between OAs and YAs, $t(47)=-5.36, p<.001$, suggesting that OAs in the current sample had reduced processing speed and inhibitory processes. There were no other group differences (see Table 2).

----- Insert Table 2 about here -----

4.1.2-Mnemonic similarity index

A 2(Group: YA vs. OA) x 2(Directed forgetting: remember vs. forget) x 5(Degree of rotation: repeat-55°) repeated-measures ANOVA with group as a between-subjects factor and directed forgetting instruction and degree of rotation as within-subject factors was used to analyze performance across the degrees of rotation (see Figure 2). There was a significant main effect of rotation, $F(1,48)=114.81, p<.001, \eta_p^2=.71$, indicating that performance improved as the

degree of rotation increased. There was no significant main effect of directed forgetting, $F(1,48)=2.47$, $p=.123$, $\eta_p^2=.05$; however, there was a trend toward a significant main effect of group, $F(1,48)=3.41$, $p=.071$, $\eta_p^2=.07$, and there was a significant three-way interaction between group, directed forgetting, and degree of rotation, $F(4,192)=2.69$, $p=.032$, $\eta_p^2=.05$. No other effects were significant, all $ps>.200$.

To probe the 3-way interaction we conducted linear contrasts between each group for the to-be-remembered and to-be-forgotten trials. For remember trials, there was a marginally significant interaction between the linear trend and age, $F(1,48)=3.02$, $p=.089$, $\eta_p^2=.06$, such that YAs exhibited a steeper slope as compared to OAs. For forget trials there was no significant interaction between the linear trend and age, $F(1,48)=1.15$, $p=.290$, $\eta_p^2=.02$. Taken together, the results suggest that YAs, as compared to OAs, are better able to engage inhibitory processes in the forget, as compared to the remember, condition.

----- Insert Figure 2 about here -----

4.2-Discussion

The current experiment tested the hypothesis that OAs, due to impaired inhibitory processes, would show no effect of the directed forgetting manipulation, while YAs would show reduced memory when instructed to forget objects, especially for lure trials. The results provide evidence that OAs exhibit a deficit in lure trial performance and that YA's performance was sensitive to the directed forgetting manipulation whereas OA's performance was not. This is supported by a significant three-way interaction in the MSI performance, where YAs exhibited a trend toward a steeper slope across lure trials in the remember condition as compared to OAs, but performance was similar in the forget condition between the two groups. Therefore, we conclude that reduced inhibitory processes, as measured using the item directed forgetting

paradigm, contribute to performance decrements in OAs on the mnemonic similarity task. It will be important for future research to replicate and explore this result further, potentially using less stimuli to prevent inhibitory fatigue, as several findings in this experiment trend in the hypothesized direction, but are not statistically significant.

Inhibitory processes have the potential to alter the balance between separation and completion processes by exerting control over the contents of memory at both encoding and retrieval. The directed forgetting paradigm tests whether control of the contents of memory at encoding affects recognition performance. Because younger adults are less likely as compared to OAs to indicate lure trials are old, only in the remember condition, it suggests that efficient inhibitory processes do have an impact on the balance between separation and completion processes. Older adults show a similar pattern regardless of directed forgetting; however, this is due to reduced inhibitory processes that occurs ubiquitously, and is likely related to prior trial information not being forgotten when it is no longer relevant. Thus, a bias to pattern complete may in part be mediated by reduced inhibitory function that occurs with aging.

5-General Discussion

The current study investigated the extent and nature in which domain general cognitive processes influence the age-related bias to pattern complete as measured by the mnemonic similarity task. Across two experiments, results indicated that age-related changes in performance on the mnemonic similarity task are moderated by processing speed and inhibitory processes. The results from Experiment 1 provide convergent evidence for a lure discrimination deficit in OAs at a standard rate of presentation during encoding (e.g., Holden & Gilbert, 2012; Kirwan & Stark, 2007; Stark et al., 2015; Toner et al., 2009; Yassa et al., 2011). Importantly, however, the results also suggest that longer encoding times for OAs are associated with

increased performance, and further, that shorter encoding times for YAs are associated with poorer performance. This pattern of results is likely due to the limited time mechanism (Salthouse, 1996a). The limited time mechanism suggests that OAs' reduced processing speed leads to a reduction in the cognitive operations that may be performed when a task has time constraints. In relation to the mnemonic similarity task, when OAs and YAs were given the same amount of time to form a detailed memory of an object, reductions in OAs' processing speed likely lead to a reduction in feature encoding of the to-be-remembered object, thereby resulting in weaker, more gist-based representations for the OAs (for similar ideas in YAs see Molitor, Ko, Hussey, & Ally, 2014). Thus, giving OAs more time at encoding and YAs less time at encoding served to equate performance.

Experiment 2 focused on OAs' and YAs' inhibitory processes by asking participants to forget some of the encountered objects (Lustig et al., 2007; Zacks et al., 2000). Deficient forgetting of previously encountered events prevents OAs from creating a mnemonic trace of a single event. The results suggest that MSI performance across degrees of rotation was significantly affected by the ability to remove previously encountered objects from the mental workspace. YAs, as compared to OAs, exhibited the ability to minimize the processing of a stimulus once they were given the instruction to forget, as evidenced by their matched lure trial performance. OA's performance for to-be-remembered objects, however, tended to be worse than that of YAs. This pattern of results suggests that YAs are better able to control the contents of working memory and thus better able to modulate what is encoded in long-term memory. The lack of control over the contents of working memory, therefore, likely contributed to poorer performance on lure trials where fine grain memory distinctions are needed to support memory.

The results of the current studies should be interpreted in the context of several limitations. Experiment 1 revealed a group difference in the ability to discern simple rotation whereas this difference was not observed in Experiment 2. Interestingly, YAs in Experiment 1 appear to outperform all other groups in Experiment 1 and 2, suggesting that the greater performance observed by YAs in Experiment 1 was driven by above typical performance in that group. Further, after controlling for rotation test performance, the pattern of significant results remained unchanged, providing evidence that age related performance differences on the mnemonic similarity task were not driven by simple rotation discrimination. Finally, while age-related differences in performance on the mnemonic similarity task are thought to be driven by a bias to pattern complete, it is not possible to disentangle a bias to pattern complete from a failure to pattern separate. Thus, it is possible that the manipulations effected pattern separation, and not pattern completion. Despite these limitations, the current experiments provide evidence that processing speed and inhibition moderate age related differences in performance on the mnemonic similarity test.

The current experiments extend the prior literature by specifying how domain general-cognitive processes contribute to performance on the mnemonic similarity task, a task thought to measure pattern separation and completion processes that support episodic memory. It will be critical for future research to elucidate what neural processes underlie domain general moderation of performance on the mnemonic similarity task. For example, when OAs are given more time to study the materials and form more rich memories, what neural regions or networks support the formation of these richer memories? While it is likely that the manipulations presented in the current experiments alter processing upstream to the hippocampus, it is also possible that the manipulations specifically alter hippocampal function. Distinguishing between

these two possibilities will be an important step in broadening our understanding of neural and behavioral drivers of separation and completion processes that support episodic memory across the lifespan.

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Table 1. Experiment 1 Demographic and Cognitive Testing Data

	YA	OA
N	25	25
Gender	12m/13f	7m/18f
Age	19.08 (0.29)*	69 (1.17)
Education	12.8 (0.22)*	17.88 (1.17)
Mini Mental State Exam	29.68 (0.11)	29.40 (0.18)
Digit span - forward	11.16 (0.41)	10.80 (0.47)
Digit span - backward	7.36 (0.45)	7.28 (0.47)
Trails A (sec)	20.48 (0.87)*	34.36 (3.21)
Trails B (sec)	49.16 (3.10) *	87.80 (12.11)
D-KEFS subtests		
Color naming (sec)	24.52 (0.83) *	30.48 (1.24)
Word reading (sec)	19.44 (0.75) *	22.00 (0.89)
Interference (sec)	41.48 (1.53) *	58.80 (2.95)

Note. YA=Younger adult. OA=Older adult. sec = seconds. Asterisks indicate a significant difference between groups, $p < .05$. Numbers represent means and (standard errors). 95% CI=95% Confidence intervals of the mean difference.

Table 2. Experiment 2 Demographic and Cognitive Testing Data

	YA	OA
N	25	25
Gender	7m/18f	10m/15f
Age	20.04 (0.53)*	73.22 (1.82)
Education	12.56 (0.14)*	17.67 (0.51)
Mini Mental State Exam	29.16 (0.24)	29.40 (0.16)
Digit span - forward	11.05 (0.39)	10.76 (0.41)
Digit span - backward	7.72 (0.43)	7.40 (0.49)
Trails A (sec)	22.68 (1.41)*	34.20 (1.71)
Trails B (sec)	51.20 (2.43)*	78.72 (6.27)
D-KEFS subtests		
Color naming (sec)	24.40 (0.75)*	30.72 (1.44)
Word reading (sec)	18.20 (0.47)*	22.32 (0.78)
Interference (sec)	39.88 (1.42)*	61.64 (3.55)

Note. YA=Younger adult. OA=Older adult. sec = seconds. Asterisks indicate a significant difference between groups, $p < .05$. Numbers represent means and (standard errors).

Figure 1. *Mnemonic Similarity Index Across all Degrees of Rotation.* Performance on repeats and lure trials by degree of rotation, age, and speed of presentation. In the standard rate of presentation younger adults exhibited a steeper slope across degree of rotation as compared to older adults, $p=.002$. In the non-standard rate of presentation younger and older adults exhibited similar slopes, $p=.117$. Both groups showed improvements in slope, as compared to themselves, for the longer encoding condition, $ps<.037$. Standard=2.5sec presentation rate for both age groups. Non-standard=1.5sec for younger adults and 5sec for older adults. Error bars represent one standard error of the mean.

Figure 2. *Mnemonic Similarity Index Across all Degrees of Rotation.* Performance on repeats and lure trials by degree of rotation, age, and directed forgetting instructions. For to-be-remembered objects, younger adults exhibited a trend, $p=.089$, for steeper slopes across degree of rotation as compared to older adults. There was no difference in slopes between groups for to-be-forgotten trials. Remember=objects instructed to be remembered. Forget=objects instructed to be forgotten. Error bars represent one standard error of the mean.