THE DIFFERENTIAL EFFECTS OF PRESENTATION RATE AND RETENTION INTERVAL ON MEMORY FOR ITEMS AND ASSOCIATIONS IN YOUNGER ADULTS: A SIMULATION OF AN AGE-RELATED ASSOCIATIVE DEFICIT

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The undersigned, appointed by the dean of the Graduate School,

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THE DIFFERENTIAL EFFECTS OF PRESENTATION RATE AND RETENTION INTERVAL ON MEMORY FOR ITEMS AND ASSOCIATIONS IN YOUNGER ADULTS: A SIMULATION OF AN AGE-RELATED ASSOCIATIVE DEFICIT

Presented by Matt Brubaker

A candidate for the degree of

Master of Arts

And hereby certify that, in their opinion, it is worthy of acceptance.

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Abstract

Older adults show an associative deficit in episodic memory compared to younger adults. Previous research suggests two underlying brain areas, the frontal lobe (FL) and the medial temporal—hippocampal area (MTL/H), as potential mediators of this deficit. However, research remains unclear as to the effects of these brain areas on age-related associative deficits. Using behavioral manipulations suggested to reflect the operation of these brain areas, three experiments were conducted to separate out the effects of FL and MTL/H by simulating the associative deficit in younger adults. In Experiment 1, item and associative recognition memory were tested while manipulating the time at encoding and retrieval (1.5 seconds vs. 6 seconds) to simulate FL deficits, and the retention interval (1 minute vs. 10 minutes) to simulate MTL/H deficits. In Experiment 2, the retention interval manipulation was further strengthened by lengthening the long delay time to 24 hours. Due to possible floor effects in Experiment 2, one final experiment was conducted in order to raise overall performance with the use of repetition at study. Results indicate that both manipulations seem to contribute equally yet independently to the associative deficit. Some questions still remain about the additive/interactive effect of both manipulations in combination.

Introduction

Memory performance tends to decline with age. However, this decline does not seem to be a global effect, encompassing all types of memory equally. Rather, while episodic memory (e.g. the temporal-spatial recollection of personal events) shows marked decline in older adults (Zacks, Hasher, & Li, 2000) semantic memory (e.g. memory for facts) remains relatively intact (Kausler & Puckett, 1980). For example, older adults may have a hard time remembering what they ate for lunch yesterday (episodic memory), but be able to recite who the first president of the United States was (semantic memory) without much difficulty.

Just as age-related decline varies across these more general types of memory, within episodic memory there are differences, as well. Chalfonte and Johnson (1996) set up an experiment in which younger and older adults studied an array of pictures, and were then tested over their memory for the individual features (e.g. item; location; color) and the bound features (e.g. item and location; item and color) of the picture arrays. Even though both tasks involve episodic memory, the results showed that, in comparison to younger adults, older adults performed worse in the binding conditions vs. the feature conditions. They suggested that this age-related deficit in feature-binding is not due to an inability to remember particular features of an event, but in an inability to bind the features together.

The Associative Deficit Hypothesis

This concept of an age-related feature-binding deficit was taken a step further by Naveh-Benjamin (2000) when he proposed the associative deficit hypothesis (ADH) to account for this specific age-related memory decline on a more general scope. The ADH does not limit the deficit to feature-binding, but predicts an age related deficit for bindings of all types of information as well as in subsequent retrieval of these bindings. Naveh-Benjamin (2000) tested this hypothesis with word/non-word pairs and unrelated word pairs by using separate tests to measure memory for the individual components (i.e. items) of an event versus the associations of paired items of an event. Results supported the ADH, showing older adults' increased deficit for associations versus items in comparison to younger adults. This hypothesis has continually proven to be quite reliable. A recent meta-analysis looking at 90 studies (Old & Naveh-Benjamin, 2008) provided even further evidence for the robust nature of this age-related associative deficit across many modalities, stimuli, and test formats.

Brain Areas that Mediate the Associative Deficit

One way to better understand this associative deficit in older adults has been to look at the underlying brain areas that may mediate it. The frontal lobe (FL), which plays an important role in executive functioning and strategic processing, and the medial-temporal—hippocampal area (MTL/H), which is responsible for memory storage and consolidation, have both been suggested to play a role in the associative deficit of older adults (Dennis et al., 2008; Glisky, Polster, & Routhieaux, 1995; Kan, Giovanello, Schnyer, Makris, & Verfaellie, 2007; Mitchell, Johnson, Raye, & D'Esposito, 2000; Raz et al., 2005).

From a structural neuro-imaging standpoint, Raz et al. (2005) used a longitudinal study to track changes in brain volumes over a five year span in healthy adults. They noted substantial decline over time, especially in older adults, in several brain areas overall, including lateral prefrontal cortex and the hippocampus. In fact, the hippocampus' rate of decline was positively correlated with increasing age, meaning that the older the subjects were at the start of the study, the more shrinkage that occurred to their hippocampus.

A functional neuro-imaging study by Mitchell et al. (2000) reported that younger (but not older) adults showed greater activation in left anterior hippocampus during feature combination (i.e. associative) short-term memory tasks versus single feature (i.e. item) short-term memory tasks. The medial frontal gyrus (an area within the pre-frontal cortex) also showed a similar age by condition interaction.

Another functional neuro-imaging study expounded upon the findings of Mitchell et al. (2000) by using pictures of faces and scenes in a long-term memory paradigm to serve as more complex stimuli than simple features (Dennis et al., 2008). After studying pictures of faces, scenes, and face/scene combinations during separate blocks, participants were given separate recognition tests to measure their memory for the faces and scenes individually (i.e. item memory), as well as for the face/scene combinations (i.e. source memory—a type of associative memory). Similar to the findings by Mitchell et al. (2000), Dennis et al. (2008) found that younger (but not older) adults showed greater activation in the hippocampus and the lateral prefrontal cortex during source memory tasks versus single item memory tasks. In fact, older adults showed relatively less activation in the lateral prefrontal cortex during source memory versus item memory tasks. The behavioral measures in this study replicated the pattern of the age-related associative deficit.

Neuroimaging methods are not the only way to measure the FL and MTL/H when comparing item versus associative memory. Glisky et al. (1995) gave older adults nine neuropsychological tests designed to measure either FL functioning or MTL/H functioning. Participants then completed a source memory task in which they listened to 40 random sentences, each spoken by one of two voices. They were then tested over their memory for the sentences (i.e. item) and which voice spoke each sentence (i.e. source). The results showed that high-functioning FL participants performed significantly better than low-functioning FL participants in source memory, with no significant differences in item memory. However, source memory was not found to be significantly different when split between high and low-functioning MTL/H participants.

Kan et al. (2007) also used indirect measures of MTL/H functioning by comparing amnesic patients (with MTL lesions) to healthy controls. In their study, participants studied lists of unrelated cue/target word-pairs and were tested over their memory for the target words under three conditions: a cued-recognition test where the original cued word was presented; a cued-recognition test with a recombined cued word; and a recognition test where only the target words were presented. The results showed that while the healthy control participants were able to perform significantly better in the first condition versus the other two, the amnesic patients performed similarly on all three conditions. These results suggest that the amnesic patients were not able to take advantage of the context (i.e. associative) effects provided by the cued word, whereas healthy participants were.

While all of these previous studies highlighted the importance of either the FL or the MTL/H to memory for associations and their contributions to the age-related associative deficit, it still remains unclear which, if either, has a greater behavioral mediating effect on this deficit. Therefore, the current study is not only an attempt to better understand the behavioral consequences of the operation of these brain structures, but also to separate out their differential effects on the associative deficit. The goal will be to simulate older adults' associative deficit in younger adults by separately manipulating variables shown to modulate the operation of the FL and MTL/H using a behavioral paradigm.

Processes Mediated by the Frontal Lobe and Medial Temporal Lobe/Hippocampus

In order to manipulate the effects of the FL and MTL/H, first it will be necessary to understand what behavioral processes are mediated by each brain area. Research has shown that the FL is responsible for overall executive functioning, and in particular strategy utilization in complex memory tasks (Kirchhoff, 2009). So it would make sense that one way to diminish strategy effects in younger adults (as a simulation of older adults' performance) would be by reducing time at encoding so that participants will not have enough time to engage in strategic methods of associating the components of a given study pair. Likewise, manipulating the response time at test will not allow participants the necessary time to utilize strategies at retrieval, either. There are studies that suggest that decreased time at encoding and retrieval indeed limit the amount of strategic-effortful processes. After manipulating the time at encoding (2 seconds vs. 5 seconds), Bunce and Macready (2005) compared younger and older adults' memory for words by looking at recollection vs. familiarity. Whereas amount of recollection increased in the five-second condition compared to the two-second condition in younger adults, time at encoding did not have an effect on recollection scores of the older adults.

The authors suggest that this is due to the younger adults' ability to utilize more executive functioning (i.e. strategy) when given more time.

Limiting retrieval time may also reduce the strategic processes that participants employ. A study by Light, Patterson, Chung, & Healy (2004) tested associative memory while manipulating the repetition of studied pairs and the response deadline at test. They found that when given only one second to respond at test (as compared to 3 seconds), younger adults showed higher false alarm rates for repeated pairs. These results suggest that the time manipulation caused the younger adults to rely on familiarity more so than recollection (see below).

Based on the standard dual-process model of memory, episodic events can be remembered based on two types of memory—familiarity or recollection (Gardiner, 1988; Tulving, 1985; Yonelinas, 2002). Whereas recollection involves a detailed remembering of the context of an event and is usually a slower, more deliberate process, familiarity simply involves an automatic "sense of knowing" without being able to give contextual information as to why. Evidence suggests that recollection tends to break down in old age, while familiarity stays relatively intact (Jennings & Jacoby, 1997). Consistent with this idea, when looking at proportion of hits and proportion of false alarms separately (as opposed to the overall measure of hits minus false alarms), it has been shown that the associative deficit seems to be due more to a higher rate of false alarms (as opposed to lower rate of hits) in older adults' associative memory (Kilb & Naveh-Benjamin, 2011; Naveh-Benjamin et al., 2009). Such a high false alarm rate reflects the reliance on familiarity (both components of a recombined pair are familiar) in the absence of recollection of the original pair. The Bunce & Macready (2005) study and the Light et al.

(2004) study show younger adults' increased reliance on familiarity when encoding and retrieval times are cut, respectively.

In addition to controlled strategy use, there is also an automatic component to associative memory, which appears to be mediated by the MTL/H. Research from neuropsychological case studies has shown that impairment to the hippocampus negatively affects inter-item associative memory more so than individual item memory (see Mayes et al., 2004), suggesting that the hippocampus is responsible for the binding of associative memories. Unlike in the frontal lobe, this binding is thought to be more automatic. Naveh-Benjamin (2000) showed support for this automatic component of associative memory by testing younger and older adults' associative memory for unrelated word-pairs under both incidental and intentional encoding. In the intentional encoding condition, participants were given instructions to pay attention to which words were presented together. In the incidental encoding condition, participants were given instructions to pay attention to which individual words were presented. If the associative deficit is due only to older adults' lack of strategy use, then the associative deficit should be eliminated in the incidental encoding condition because neither younger nor older adults would have used a strategy at encoding. However, results showed an associative deficit (albeit smaller) in the incidental learning condition as well as in the intentional condition, suggesting that there is an automatic process binding associations together that is impaired in older adults. In an attempt to manipulate this automatic binding of associations, the current study varied the retention interval between short and long durations. The assumption underlying this manipulation is that the delay would negatively affect automatic binding of the associations in the hippocampus more so than for individual item memory. A recent study by Vakil, Raz, & Levy (2010) attempted to manipulate MTL/H effects by using an extended retention interval. After younger adult subjects studied pictures of faces each wearing various hats (with intentional memory for faces only), results showed that the hats affected the memory for the faces (i.e. context effects) following an immediate delay. However, these context effects were minimized following a one week delay. These results suggest that context effects (a type of associative memory) are negatively affected by prolonged retention intervals which attenuate automatic binding while retaining item information.

Experiment 1

In the first experiment, we tested younger adults' item and associative memory for face/scene picture pairs while manipulating the time at encoding/retrieval (1.5 seconds vs. 6 seconds) to simulate FL deficits, and manipulating the time at retention (1 minute delay vs. 10 minute delay) to simulate MTL/H deficits. The reason for using 1.5 seconds (and not a shorter rate) and only a 10 minute delay is an attempt to avoid floor effects under the combination of those conditions.

A recent study by Kilb & Naveh-Benjamin (2011) provided support for an age-related associative deficit using face/scene picture pairs—similar to the stimuli used in the current study. Their results showed that whereas older adults' memory performance for the items (either the individual faces or the individual scenes) was similar to that of younger adults, the older adults' memory for the associations (which faces and scenes were originally paired together) was significantly poorer than that of younger adults (see Figure 1). Also, as discussed earlier, this age-related associative deficit appears to be due more to an increase in false alarms in the associative test for older adults relative to younger adults, as opposed to a decrease in hits (see Figure 2). These results demonstrate the associative deficit in older adults, which we will attempt to simulate in younger adults by manipulating the presentation rate and retention interval in the current study.

Figure 1. Results of Proportion Hits minus False Alarms from Kilb & Naveh-Benjamin (2011)

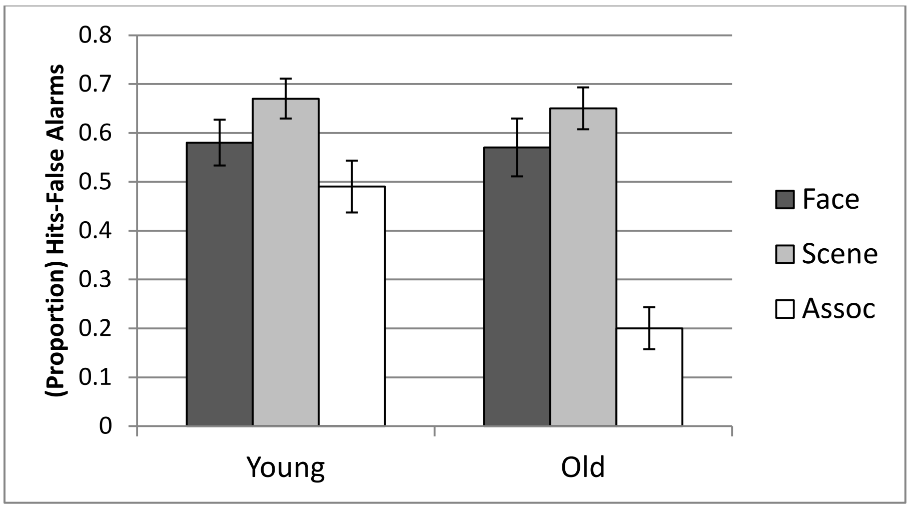
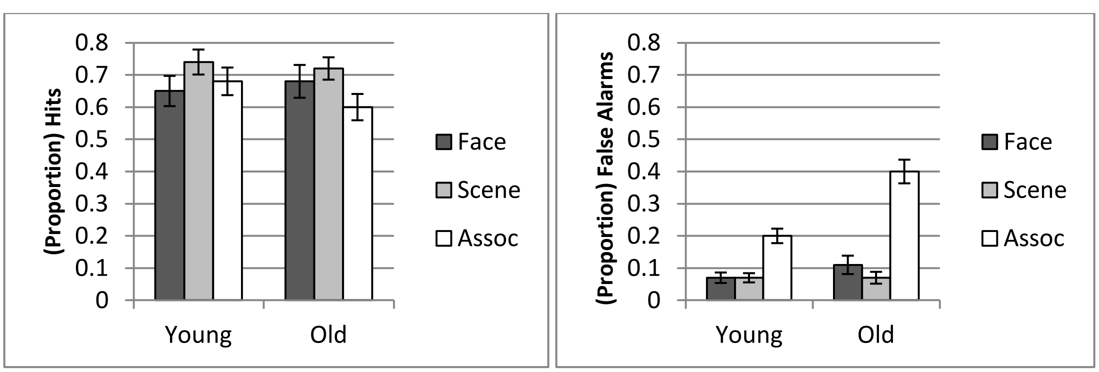


Figure 2. Proportion Hits and Proportion False Alarms from Kilb & Naveh-Benjamin (2011)



Overall, we expected to see main effects of encoding/retrieval rate and retention interval, with the shorter presentation rate and longer retention interval resulting in overall poorer memory performance, respectively. And based on previous research using this paradigm (Naveh-Benjamin, 2000), we expected a main effect of test, with overall poorer associative memory scores relative to item scores.

More importantly, if the associative deficit is mediated by the FL, we expected an interaction of encoding/retrieval time with test, with the shorter presentation rate resulting in poorer associative relative to item performance. If the associative deficit is mediated by the MTL/H, we expected an interaction of retention time with test, with the longer retention interval resulting in poorer associative relative to item performance. Based on previous research (Kilb & Naveh-Benjamin, 2011; Naveh-Benjamin, et al., 2009), the differential associative deficit in both of the 2-way interactions above should be driven primarily by an increase in associative false alarms as opposed to a decrease in associative hits. If so, we would expect to see a large main effect of test when looking at just proportion false alarms, but a small to minimal main effect of test when looking at just proportion hits.

Finally, we expected that the poorest associative (vs. item) performance would be in the short presentation rate and long retention interval condition due to an additive effect of both manipulations in combination. However, if the associative deficit is mediated by the interaction of the FL and the MTL/H, we would expect a triple interaction of rate of presentation, retention interval, and test, with a disproportionately larger associative deficit in the short presentation rate and long retention interval condition.

Method

Participants

The participants included 42 undergraduate students enrolled in an introductory psychology course at the University of Missouri who were offered class credit for their involvement. Five of the students' data were not analyzed because they did not follow instructions and/or their performance level was at or below chance during the baseline condition. The remaining 37 participants had an average age of 19.30 years (SD=1.45, range of 18-24 years), an average education level of 12.62 years (SD=1.16, range of 12-17 years), and 20 of them were females.

Design

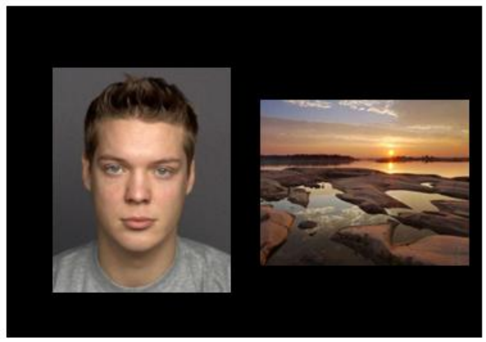
This experiment used a 2 (test: item vs. associative) x 2 (rate of presentation at encoding and retrieval: short vs. long) x 2 (retention interval: short vs. long) design. All factors were within-subjects.

Materials

This experiment was run using the E-Prime program software (version 2.0). Stimuli consisted of picture pairs of faces and scenes (in color) that were shown to participants on a 15 inch computer screen, with resolution set at 640 x 480 pixels (see an example in Figure 3). Images were 230 x 288 pixels, and either appeared centered side by side on the screen (during study phase and associative test phase), or individually centered on the screen (during item test phases). The faces, which all had emotionally neutral expressions, were taken from the FACES database (Ebner, Riediger, &

Lindenberger, 2010), developed at the Max Planck Institute for Human Development in Berlin, with an equal number of younger and older adults as well as male and female. The scenes were a collection of random scenic images pulled from an online Google search, and included mountains, oceans, fields, beaches, cities, and roads.

Figure 3. Example of a Face/Scene Picture Pair from Experiment 1



Four trial blocks were run, each consisting of a study phase (30 picture-pairs), followed by separate item recognition test phases for the faces (20 items—10 from the study phase; 10 new) and the scenes (20 items—10 from the study phase; 10 new), and an associative recognition test phase for the pairs (20 items—10 intact pairs from the study phase; 10 recombined pairs from the study phase). The order of the test phases was counterbalanced between subjects. Each study and test phase was split into two ordered halves, with half the items appearing on the screen for 6 seconds, and the other half for 1.5 seconds (with order counterbalanced between blocks). The manipulation of rate of presentation within block was in order to have each study and test phase be of equal time duration.

A one minute retention interval followed the study phase in two of the blocks, and a 10 minute retention interval followed the study phase in the other two blocks (with order counterbalanced between blocks). An interpolated activity during both the short and long retention intervals consisted of filling out a word-search puzzle. Because the interpolated activity was verbal in nature, it should not interfere with the picture stimuli shown during the study phase.

Procedure

Participants were given instructions to study the picture pairs during the study phase and be prepared for the face, scene, and associative memory tests to follow, which included an equal number of old (targets/intact pairs) and new (distractors/recombined pairs) items. A practice block was given following the instructions so that participants could become familiar with the procedure before beginning the first trial block. Participants then viewed the study phase of the first block consisting of 30 picture pairs, with each of the first 15 study items appearing on the screen for either 6 seconds or 1.5 seconds. A 500 ms inter stimulus interval (ISI) separated each study item, followed by an additional 500 ms cue screen (with a fixation cross in the center of the screen) after the 15^{th} study item, alerting participants that the rate of presentation will change for the remaining 15 items in the study phase. After completing the interpolated activity for one minute or 10 minutes, the three recognition tests took place. A 250 ms fixation cross appeared immediately before each test item, alerting participants to get ready to respond. Each of the first 10 items during each test phase appeared for either 6 seconds or 1.5 seconds (based on the same order as the study phase), followed by a brief (1 second) blank screen, in order to "catch" any late responses. During the item recognition tests (for the faces and the scenes), 20 single items were presented on the screen, and participants were instructed to respond whether or not they recognized the item by pressing "V" for old items (that appeared during the study phase; i.e. targets), and “N” for new items (that did not appear during the study phase; i.e. distractors). During the associative recognition test, 20 face/scene picture pairs were presented on the screen, and participants were instructed to respond whether or not they recognized that same pair appearing together at study by pressing “V” for intact pairs (the same pictures appeared together during the study phase), and “N” for recombined pairs (each picture initially appeared with a different picture during the study phase). Participants were informed that there were an equal number of old and new items during each test phase.

After all four trial blocks were completed, a post-test questionnaire was given to each participant, followed by debriefing.

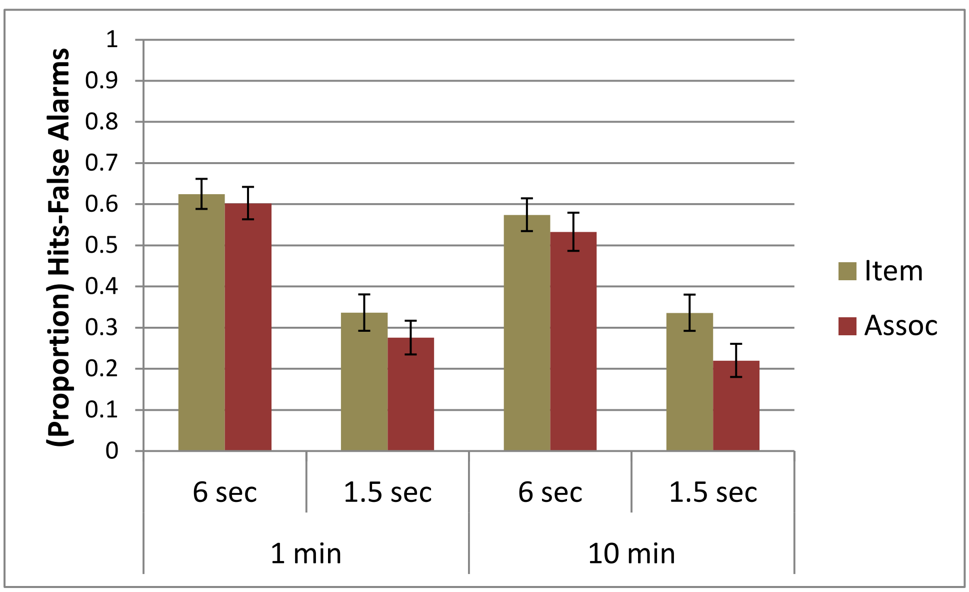
Results

Overall, memory accuracy was measured by computing proportion hits (proportion of “V” responses to targets) minus proportion false alarms (proportion of “V” responses to distractors). The means and standard deviations for each condition are listed in Table 1, while the means and standard errors are shown in the graph in Figure 4.

Table 1. *Proportion Hits minus False Alarms Means and Standard Deviations from Experiment 1*

	1 min. Retention				**10 min. Retention**			
	6 sec. Rate		**1.5 sec. Rate**		**6 sec. Rate**		**1.5 sec. Rate**	
Item (SD)	.62	(.19)	.34	(.22)	.57	(.19)	.34	(.22)
Assoc(SD)	.60	(.24)	.28	(.25)	.53	(.28)	.22	(.25)

Figure 4. Results of Proportion Hits minus False Alarms from Experiment 1

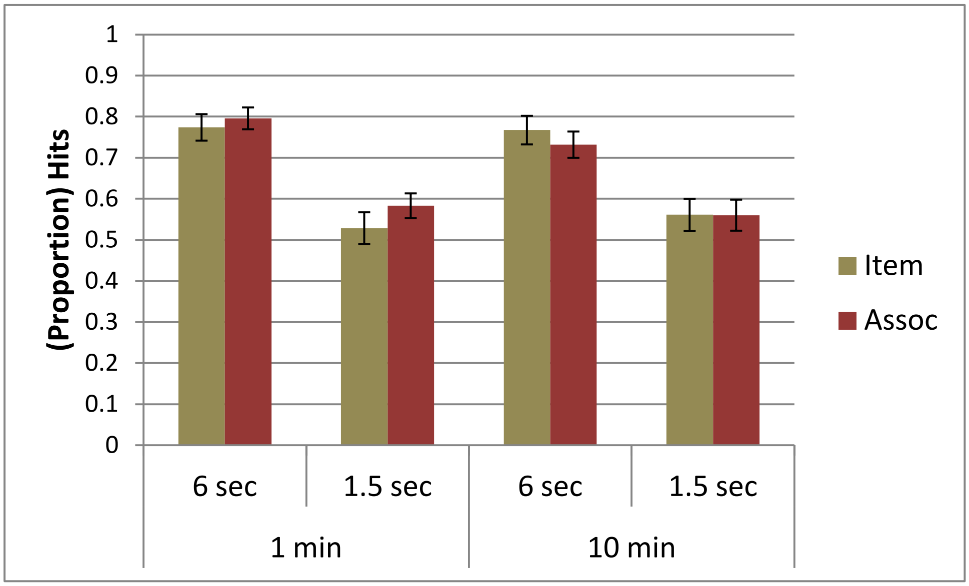


A three-way ANOVA was performed with rate of presentation, retention interval, and test as the independent variables, and proportion of hits minus false alarms as the dependent variable. As expected, there was a significant main effect of rate of presentation ($F(,1,36)=164.63$, $\eta_p^2=.82$, $p<.001$), with higher memory performance for the long rate (M=.58, SD=.18) than the short rate (M=.29, SD=.17). There was a significant main effect of retention interval ($F(1,36)=4.32$, $\eta_p^2=.11$, $p<.05$), with higher memory performance following the short retention (M=.46, SD=.16) than following the long retention (M=.42, SD=.19). There was also a significant main effect of test ($F(1,36)=5.31$, $\eta_p^2=.13$, $p<.05$), with item test performance (M=.47, SD=.16) being higher than associative test performance (M=.41, SD=.20).

No significant three-way interaction was shown between presentation rate, retention interval, and test ($F(1,36)=.39$, $\eta_p^2=.01$, $p=.54$). Also, no significant interactions were shown between presentation rate and test ($F(1,36)=1.62$, $\eta_p^2=.04$, $p=.21$), between retention interval and test ($F(1,36)=1.09$, $\eta_p^2=.03$, $p=.30$), or between retention interval and presentation rate ($F(1,36)=.803$, $\eta_p^2=.02$, $p=.38$). Planned comparison ANOVA's revealed a marginally significant interaction of test comparing the short rate/long retention condition against the long rate/short retention condition ($F(1,36)=2.87$, $\eta_p^2=.07$, $p=.099$). However, there was no significant interaction of test comparing the short rate/short retention condition against the long rate/short retention condition ($F(1,36)=.50$, $\eta_p^2=.01$, $p=.48$), or of test comparing the long rate/long retention condition against the long rate/short retention condition ($F(1,36)=.26$, $\eta_p^2=.01$, $p=.61$).

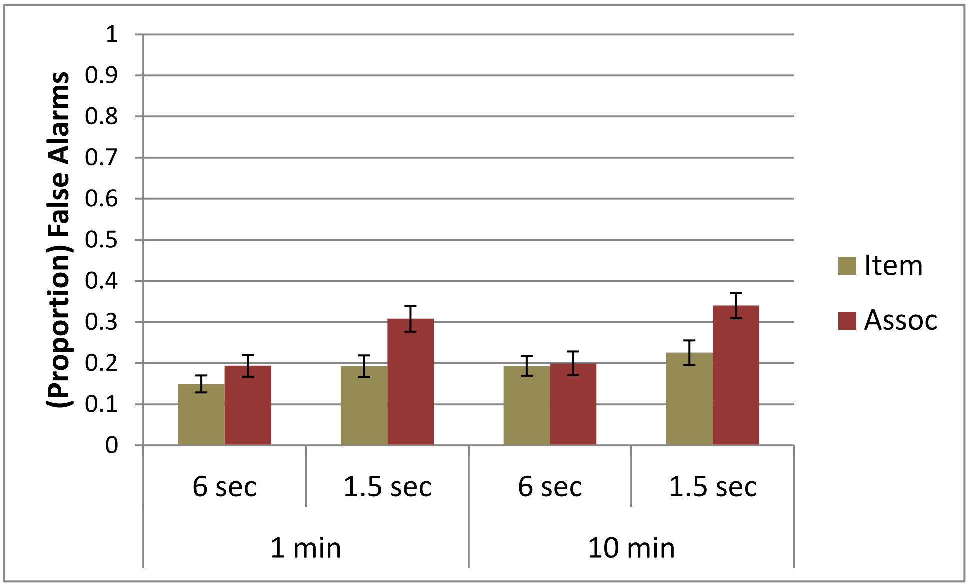
Next, proportion hits and proportion false alarms were analyzed separately. Examining proportion hits (see Figure 5), there was a significant main effect of presentation rate ($F(1,36)=105.33$, $\eta_p^2=.75$, $p<.001$), with higher proportion hits for the long rate (M=.77, SD=.14) than the short rate (M=.56, SD=.16). There were no significant main effects of either retention interval ($F(1,36)=.97$, $\eta_p^2=.03$, $p=.33$) or test ($F(1,36)=.27$, $\eta_p^2=.01$, $p=.61$). The only significant interaction was that of test and retention interval ($F(1,36)=4.38$, $\eta_p^2=.11$, $p<.05$). Follow-up t-tests of the interaction between test and retention interval showed a marginally significant difference of proportion hits in the associative test between the long retention interval ($M=.65$, $SD=.18$) and the short retention interval ($M=.69$, $SD=.14$), $t(36)=1.94$, $p=.06$, but no significant difference of proportion hits in the item test between the long retention interval ($M=.66$, $SD=.17$) and the short retention interval ($M=.65$, $SD=.16$), $t(36)=.70$, $p=.49$. Similarly, there was a marginally significant difference of proportion hits in the short retention interval between the item test ($M=.65$, $SD=.16$) and the associative test ($M=.69$, $SD=.14$), $t(36)=1.71$, $p<.10$, but no significant difference of proportion hits in the long retention interval between the item test ($M=.66$, $SD=.17$) and the associative test ($M=.65$, $SD=.18$), $t(36)=.74$, $p=.46$. This lack of significant differences is due to the cross-over nature of the interaction, which indicates that lengthening the retention interval decreased the proportion hits in the associative test while actually increasing proportion hits in the item test, and that proportion hits increased in the associative test compared to the item test after the short retention while it decreased in the associative test compared to the item test after the long retention interval.

Figure 5. Proportion Hits from Experiment 1



Examining the proportion false alarms (see Figure 6) showed a significant main effect of presentation rate ($F(1,36)=41.61$, $\eta_p^2=.54$, $p<.001$), with a higher proportion of false alarms at the short rate ($M=.27$, $SD=.13$) than the long rate ($M=.18$, $SD=.10$). There was also a significant main effect of retention interval ($F(1,36)=4.68$, $\eta_p^2=.12$, $p<.05$), with a higher proportion of false alarms following the long retention ($M=.24$, $SD=.12$) than following the short retention ($M=.21$, $SD=.12$). A significant main effect of test was also found ($F(1,36)=16.10$, $\eta_p^2=.31$, $p<.001$), with a higher proportion of false alarms on the associative test ($M=.26$, $SD=.14$) than on the item test ($M=.19$, $SD=.10$).

Figure 6. Proportion False Alarms from Experiment 1



No significant three-way interaction was found between presentation rate, retention interval, and test ($F(1,36)=1.08$, $\eta_p^2=.03$, $p=.31$). The only significant two-way interaction found was between presentation rate and test ($F(1,36)=6.54$, $\eta_p^2=.15$, $p<.05$). Follow-up t-tests indicated a significant difference in performance on the item test between the long presentation rate (M=.17, SD=.09) and the short presentation rate (M=.21, SD=.12), $t(36)=2.42$, $p<.05$, and more importantly a larger significant difference in performance on the associative test between the long presentation rate (M=.20, SD=.16) and the short presentation rate (M=.32, SD=.17), $t(36)=4.81$, $p<.001$. To show that this effect of presentation rate on associative memory was larger than that on item memory, the difference scores for false alarm rates between the short and long presentation rates were computed for the associative (M=.13, SD=.16) and the item (M=.04, SD=.09) tests . This difference was significantly larger for the associative than for the item test ($t(36)=2.56$, $p<.05$), indicating that shortening the presentation rate increased the proportion of false alarms in the associative test more than in the item test.

Discussion

The results show that overall performance (proportion of hits minus false alarms) declines when the rate of presentation is shortened, and also when the retention interval is lengthened, although the effect of rate is much stronger than retention as evidenced by the main effect sizes of each. There is a trend of an associative deficit when both presentation rate and retention interval are manipulated (as evidenced by the marginally significant planned comparison). However, none of the main interactions are significant. As expected, this trend was driven by test differences in false alarms, and not hits. The proportion of false alarms showed an increase during associative versus item tests (in line with the age-related associative deficit), but only when the presentation rate was shortened, and not when the retention interval was lengthened. This is in line with the involvement of the frontal lobe in associative memory decline. One possibility is that the manipulation of the retention interval was too weak and that if the long retention interval were lengthened then proportion hits might be lower and proportion false alarms higher in the associative test.

Experiment 2

In Experiment 1, a trend towards an associative memory deficit appears to be simulated with the combined manipulation of both rate of presentation and retention, but not with either manipulation by itself. The manipulation of the presentation rate does increase false alarms in the associative test significantly more than the item test, yet the manipulation of the retention interval does not show a similar interaction. One possible problem is that the manipulation on the retention interval might have been too weak. In experiment 1, 10 minutes was used as the long retention condition in order to avoid any potential floor effects. Since performance was above floor in the condition involving the combined manipulation of presentation rate and retention interval, in order to strengthen the manipulation of the retention interval in Experiment 2, a similar procedure was run using a 24 hour long retention interval condition, which is also more consistent with previous studies (Vakil et al., 2010). In order to minimize proactive interference between multiple trial blocks during the 24 hour delayed memory tests, only two trial blocks were used in Experiment 2, as opposed to the four that were used in Experiment 1. In Experiment 2, we expect to see main effects similar to Experiment 1. And if the retention manipulation is strong enough, we expect to see an interaction of test and presentation rate as well as of test and retention interval, with associative test performance being significantly more affected than item test performance. Finally, assuming an additive effect of both manipulations when combined, we expect to see the largest associative deficit in the short rate/long retention condition.

Method

Participants

The participants included 43 undergraduate students enrolled in an introductory psychology course at the University of Missouri who were offered class credit for their involvement. Six of the students' data were not analyzed because they did not follow instructions and/or their performance level was at or below chance during the baseline condition. The remaining 37 participants had an average age of 20.54 years (SD=1.77, range of 18-24 years), an average education level of 14.14 years (SD=1.49, range of 12-17 years), and 21 of them were females.

Design

This experiment used a 2 (test: item vs. associative) x 2 (rate of presentation at encoding and retrieval: short vs. long) x 2 (retention interval: short vs. long) design. All factors were within-subjects.

Materials

All stimuli were the same as those used in Experiment 1. Two trial blocks were used, each consisting of a study phase (48 picture-pairs), followed by two separate sets of item recognition test phases for the faces (16 items in each—8 from the study phase; 8 new), two separate sets of item recognition test phases for the scenes (16 items in each—8 from the study phase; 8 new), and two separate sets of associative recognition test phases for the pairs (16 items each—8 intact pairs from the study phase; 8 recombined pairs from the study phase). The order of the test phases was counterbalanced between subjects. Presentation rates were the same as in Experiment 1.

A one minute retention interval followed both of the study phases, during which time the participants performed an interpolated activity (verbally counting backwards by 3's from a random number that the experimenter provided).

Procedure

This was a two-day experiment. On the first day, participants were given instructions to study the picture pairs during the study phases in order to prepare for the following recognition tests. They were informed that each test would include an equal number of old (targets/intact pairs) and new (distractors/recombined pairs) items. After a brief practice block, participants received the study phase for the first trial block followed by the first set of recognition tests (same procedure as described in Experiment 1).

After the second trial block was run, participants were informed that this was the end of the first day. They were reminded to return the next day for the second session of the experiment, but were not told what they would be doing on day two.

At the beginning of the second session, 24 hours later, participants were told that they would be tested again over the pictures they saw during both study phases the previous day. The procedure and test format was the same as day one, except without a new study phase for each block. Instead, participants were immediately given the second set of recognition tests (same test order as day one) based on the study phase of the first block from the day before. This was followed by the second set of recognition tests (same test order as day one) based on the study phase of the second block from the day before. No items that appeared during test phases on day one were repeated during test phases on day two (for example, half the pictures from the first block study phase on day one were used as targets during the first block test phase on day one, and the other half were used as targets during the first block test phase on day two).

After both test blocks were run on day two, a post-test questionnaire was given to each participant, followed by debriefing.

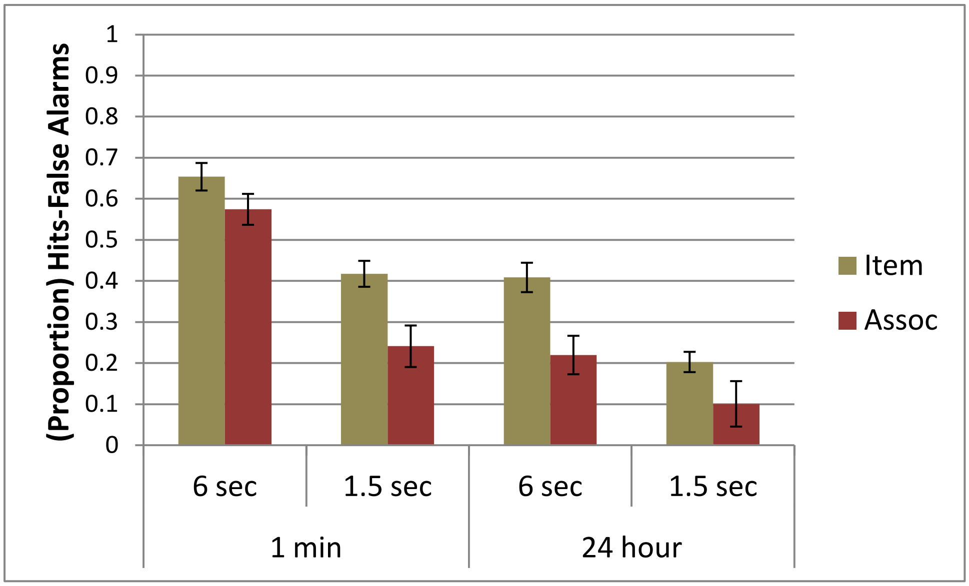
Results

Memory accuracy was measured in proportion hits (proportion of “V” responses to targets) minus proportion false alarms (proportion of “V” responses to distractors), same as in Experiment 1. The means and standard deviations are listed in Table 2, while the means and standard errors are shown in the graph in Figure 7.

Table 2. *Proportion Hits minus False Alarms Means and Standard Deviations from Experiment 2*

	1 min. Retention				**24 hr. Retention**			
	6 sec. Rate		**1.5 sec. Rate**		**6 sec. Rate**		**1.5 sec. Rate**	
Item (SD)	.65	(.20)	.42	(.19)	.41	(.22)	.20	(.15)
Assoc(SD)	.57	(.23)	.24	(.31)	.22	(.28)	.10	(.34)

Figure 7. Results of Proportion Hits minus False Alarms from Experiment 2



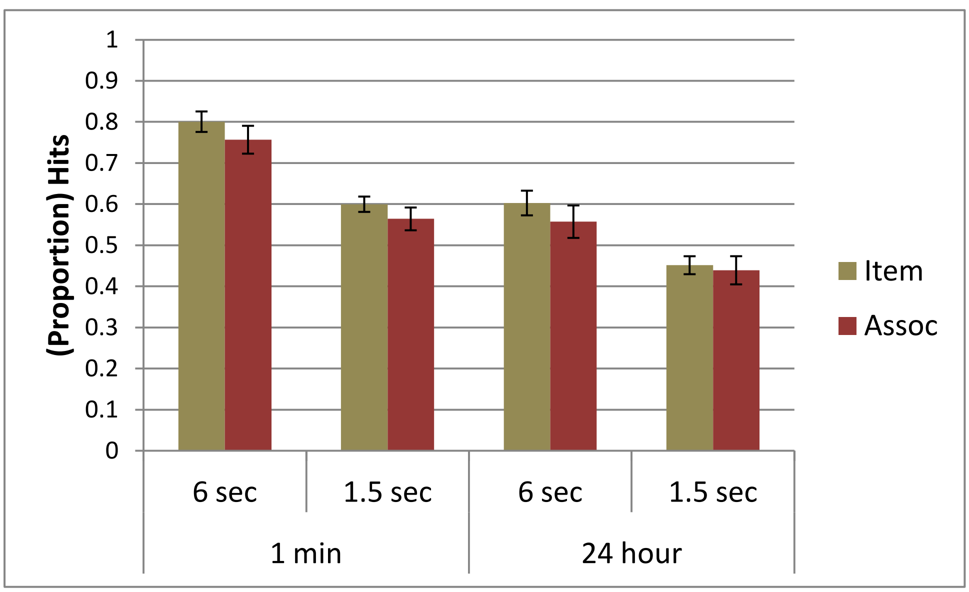
A three-way ANOVA was performed with rate of presentation, retention interval, and type of test as the independent variables, and proportion hits minus false alarms as the dependent variable. As expected, there was a significant main effect of presentation rate ($F(1,36)=44.08$, $\eta_p^2=.55$, $p<.001$), with higher performance for the long rate (M=.46, SD=.18) than the short rate (M=.24, SD=.16). There was also a significant main effect of retention interval ($F(1,36)=107.89$, $\eta_p^2=.75$, $p<.001$), with higher performance following the short retention (M=.47, SD=.15) than the long retention (M=.23, SD=.16). Finally, there was also a significant main effect of test ($F(1,36)=30.17$, $\eta_p^2=.46$, $p<.001$), with higher performance on the item memory test (M=.42, SD=.15) than the associative memory test (M=.28, SD=.16).

The three-way interaction between presentation rate, retention interval, and test was marginally significant ($F(1,36)=3.26$, $\eta_p^2=.08$, $p=.08$). The only significant interaction was between presentation rate and retention interval ($F(1,36)=7.13$, $\eta_p^2=.17$, p<.05). Follow-up t-tests of the interaction between presentation rate and retention interval revealed significant differences between all combinations of presentation rate and retention interval. Specifically, there was a significant difference between short (M=.33, SD=.20) and long (M=.61, SD=.19) presenation rates at the short retention interval (t(36)=6.91, p<.001), between short (M=.15, SD=.20) and long (M=.31, SD=.20) presentation rates at the long retention interval (t(36)=4.03, p<.001), and also between short (M=.33, SD=.20) and long (M=.15, SD=.20) retention intervals at the short presentation rate (t(36)=4.68, p<.001), and between short (M=.61, SD=.19) and long (M=.31, SD=.20) retention intervals at the long presentation rate (t(36)=11.56, p<.001).

Planned comparison ANOVAs revealed a marginally significant interaction of test comparing the long rate/long retention condition against the long rate/short retention condition (F(1,36)=3.64, η_p^2=.09, p=.06), but no significant interaction of test comparing the short rate/short retention condition against the long rate/short retention condition (F(1,36)=2.12, η_p^2=.06, p=.15), or of test comparing the short rate/long retention condition against the long rate/short retention condition (F(1,36)=.10, η_p^2=.003, p=.75).

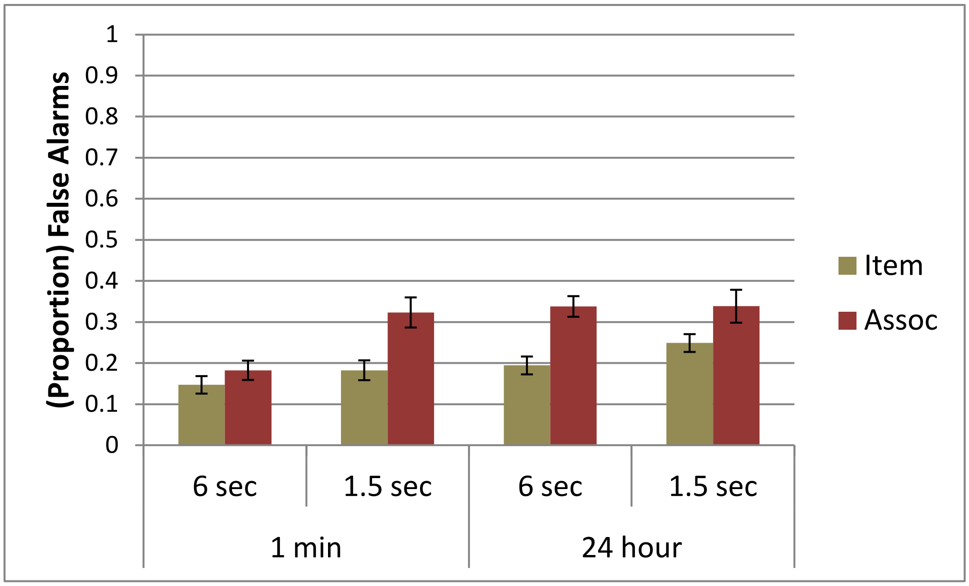
Proportion hits and proportion false alarms were analyzed separately. Examining proportion hits (see Figure 8), there was a significant main effect of presentation rate (F(1,36)=49.73, η_p^2=.58, p<.001), with higher proportion hits for the long rate (M=.68, SD=.15) than the short rate (M=.51, SD=.10), and retention interval (F(1,36)=66.09, η_p^2=.65, p<.001), with higher proportion hits for the short retention (M=.68, SD=.10) than the long retention (M=.51, SD=.14). Only a marginally signifcant main effect of test was found (F(1,36)=2.99, η_p^2=.08, p=.09), with proportion hits being slightly higher on the item test (M=.61, SD=.11) than on the associative test (M=.58, SD=.13). The only significant interaction was between presentation rate and retention interval ($F(1,36)=5.98$, $\eta_p^2=.14$, $p<.05$). Follow-up t-tests of the interaction between rate and retention revealed significant differences between all combinations of presentation rate and retention interval. Specifically, there was a significant difference between short (M=.58, SD=.11) and long (M=.78, SD=.15) presentation rates at the short retention interval ($t(36)=7.58$, $p<.001$), and between short (M=.45, SD=.13) and long (M=.58, SD=.19) presentation rates at the long retention interval ($t(36)=4.92$, $p<.001$). There was also a significant difference between short (M=.58, SD=.11) and long (M=.45, SD=.13) retention intervals at the short presentation rate ($t(36)=5.94$, $p<.001$), and between short (M=.78, SD=.15) and long (M=.58, SD=.19) retention intervals at the long presentation rate ($t(36)=7.85$, $p<.001$).

Figure 8. Proportion Hits from Experiment 2



Examining proportion false alarms (see Figure 9), there were significant main effects of presentation rate ($F(1,36)=10.18$, $\eta_p^2=.22$, $p<.01$), with higher proportion false alarms for the short rate (M=.27, SD=.13) than the long rate (M=.22, SD=.09), and of retention interval ($F(1,36)=17.96$, $\eta_p^2=.33$, $p<.001$), with higher proportion false alarms for the long retention (M=.28, SD=.12) than the short retention (M=.21, SD=.10), and of test ($F(1,36)=24.66$, $\eta_p^2=.41$, $p<.001$), with higher proportion false alarms on the associative test (M=.30, SD=.12) than the item test (M=.19, SD=.12). The three-way interaction between presentation rate, retention interval, and type of test was significant ($F(1,36)=6.60$, $\eta_p^2=.16$, $p<.05$). Follow-up two-way ANOVAs revealed a significant interaction between presentation rate and test at the short retention interval ($F(1,36)=4.77$, $\eta_p^2=.12$, $p<.05$), but not at the long retention interval ($F(1,36)=1.16$, $\eta_p^2=.03$, $p=.29$). Follow-up t-tests on the interaction between rate and test at the short retention revealed a larger significant difference of proportion false alarms on the associative test between the long rate (M=.18, SD=.14) and the short rate (M=.32, SD=.22) held constant at the short retention interval ($t(36)=3.16$, $p>.01$) than on the item test between the long rate (M=.15, SD=.13) and the short rate (M=.18, SD=.15) held constant at the short retention interval ($t(36)=1.7$, $p<.10$), $t(36)=2.18$, $p<.05$.

Figure 9. Proportion False Alarms from Experiment 2



Following up on the 3-way interaction, there was also a significant interaction between retention interval and test at the long presentation rate ($F(1,36)=9.98$, $\eta_p^2=.22$, $p<.01$), but not at the short presentation rate ($F(1,36)=1.38$, $\eta_p^2=.04$, $p=.25$). Follow-up t-tests on the significant interaction between retention and test at the long rate revealed a larger significant difference of proportion false alarms on the associative testbetween the short retention interval (M=.18, SD=.14) and the long retention interval (M=.34, SD=.15 ($t(36)=4.87$, $p<.001$) than on the item test between the short retention interval (M=.15, SD=.13) and the long retention interval (M=.19, SD=.13) ($t(36)=3.24$, $p<.01$), $t(36)=3.16$, $p<.01$.

Discussion

Results show that overall memory performance (proportion hits minus false alarms) declines when either the presentation rate is shortened or the retention interval is lengthened (indicated by significant main effects of each). This is further understood by main effects showing that proportion hits decrease and proportion false alarms increase when either the presentation rate is shortened or the retention interval is lengthened. However, as expected, the increase in false alarms is greater than the decrease in hits.

The absence of either two-way interaction (presentation rate by test, and retention interval by test) suggests no associative deficit was simulated, and the marginally significant three-way interaction is actually in the opposite direction that was predicted. For the hypothesis to hold, the associative deficit would need to increase under the combined condition of 1.5 second presentation rate and 24 hour retention interval. However, the actual results from this condition show the difference between item and associative test performance to actually be less than in the other conditions. This is also confirmed by the planned comparisons testing the long rate/short retention condition with each of the other three conditions, revealing trends (although not significant) toward an associative deficit when just the presentation rate (short rate/short retention) or just the retention interval (long rate/long retention) are manipulated, but not when both are manipulated within the same condition (short rate/long retention).

These patterns are even more evident when looking at just the proportion false alarms data. As discussed earlier, the associative memory deficit of older adults appears to be due more to an increase in false alarms during associative vs. item tests as opposed to an increase in hits (Kilb & Naveh-Benjamin, 2011; Naveh-Benjamin et al., 2009). The proportion false alarms data for Experiment 2 revealed a three-way interaction between presentation rate, retention interval, and test. Yet similar to the overall (hits minus false alarms) performance, this interaction is in the opposite direction as the hypothesis would suggest, showing a decreased difference between item and associative false alarm scores in the short rate/long retention condition, compared to an increased difference between item and associative false alarm scores when either rate or interval were manipulated separately. However, there were significant interactions between presentation rate and test at the short retention interval, and also between retention interval and test at the long presentation rate, indicating that manipulating just presentation rate or just retention interval increases false alarms in the associative test significantly more than in the item test. So this differential increase in false alarms is consistent with the data seen in older adults, suggesting that an associative deficit is being simulated in both conditions. Interestingly, this effect is reversed when both manipulations are used together (i.e. the difference in false alarms between item and associative tests is actually less than in the other conditions, including the baseline condition), suggesting that this associative deficit is actually minimized under the combination of both manipulations.

There are two possible explanations that could account for this. The first possibility is that floor effects could be effecting the results in the short rate/long retention condition. Because memory performance in this condition for the item test (M=.20, SD=.15) was low, memory performance on the associative test (M=.10, SD=.33) could only be a certain amount lower before hitting chance level performance (0.0). In other words, perhaps memory performance is so low in this condition that the associative deficit could not increase in size, as it might have had performance been better overall. The second possibility is that the 24 hour retention interval manipulation is too strong, and when the two manipulations are combined (1.5 second rate with 24 hour interval) perhaps there is now a similar effect on item memory as there is on associative memory, thus causing an additive effect on memory performance overall, but not on the magnitude of the associative deficit.

Experiment 3

The purpose of Experiment 3 was to eliminate any possible floor effects—specifically in the short rate/long retention condition—in order to assess whether an additive effect of both manipulations will cause an even larger associative deficit. In order to accomplish this goal, a repetition procedure was added in which each picture pair was presented twice during the study phase. The repetition was designed to increase memory performance overall across all conditions, so that any effects of test would not be confounded with possible floor effects. The hypotheses remain the same as in Experiment 2—main effects of presentation rate, retention interval, and type of test; and consistent with an associative deficit hypothesis, interactions between presentation rate and test, between retention interval and test, and between presentation rate, retention interval, and test.

Method

Participants

The participants included 33 undergraduate students enrolled in an introductory psychology course at the University of Missouri who were offered class credit for their involvement. Three of the students' data were not analyzed because they did not follow instructions and/or their performance level was at or below chance in the baseline condition. The remaining 30 participants had an average age of 19.23 years (SD=1.55, range of 18-26 years), an average education level of 12.40 years (SD=.67, range of 12-14 years), and 17 of them were females.

Design

This experiment used a 2 (test: item vs. associative) x 2 (rate of presentation at encoding and retrieval: short vs. long) x 2 (retention interval: short vs. long) design. All factors were within-subjects.

Materials

All stimuli were the same as those used in Experiments 1 and 2. As in Experiment 2, two trial blocks were used (with the same number of items in each study and test phase as Experiment 2). The only difference was that during the study phase each face-scene picture pair was presented twice (in a spaced manner), so that the total number of study events was 96. This repetition was blocked within each presentation rate, meaning that the first 48 study events were presented with the same presentation rate (24 pairs randomly presented, then randomly repeated), and the next 48 study events were presented with the other presentation rate (the next 24 pairs randomly presented, then randomly repeated).

One other change in Experiment 3 was that the long presentation rate condition was changed from 6 seconds to 4.5 seconds (at both study and test). Based on participant feedback and reaction time data from Experiments 1 and 2, it was concluded that 4.5 seconds might be a more efficient presentation rate—long enough for participants to still be able to use strategies at study and test, yet short enough that participants' attention would remain focused on the task.

Procedure

The procedure was the same as in Experiment 2, except that participants were told that all of the picture pairs would be repeated during the study phase.

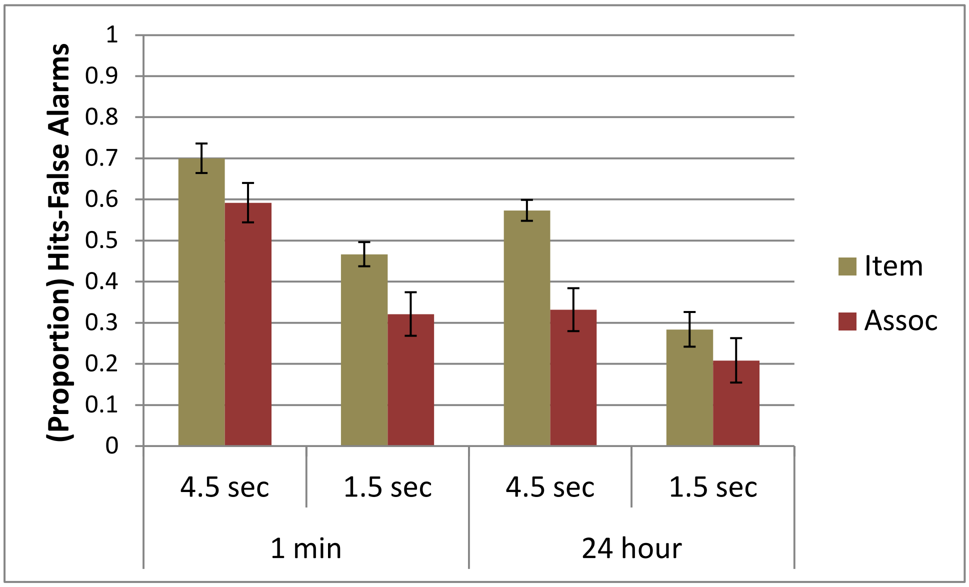
Results

Memory accuracy was measured in proportion hits (proportion of “V” responses to targets) minus proportion false alarms (proportion of “V” responses to distractors), same as in Experiment 1. The means and standard deviations are listed in Table 3, while the means and standard errors are shown in the graph in Figure 10.

Table 3. *Proportion Hits minus False Alarms Means and Standard Deviations from Experiment 3*

	1 min. Retention				**24 hr. Retention**			
	4.5 sec. Rate		**1.5 sec. Rate**		**4.5 sec. Rate**		**1.5 sec. Rate**	
Item (SD)	.70	(.20)	.47	(.16)	.57	(.14)	.28	(.23)
Assoc(SD)	.59	(.26)	.32	(.29)	.33	(.29)	.21	(.30)

Figure 10. Results of Proportion Hits minus False Alarms from Experiment 3



A three-way ANOVA was run with presentation rate, retention interval, and type of test as the independent variables and memory performance (proportion hits minus false alarms) as the dependent variable. As expected, there was a significant main effect of presentation rate ($F(1,29)=56.92$, $\eta_p^2=.66$, $p<.001$), with higher performance for the long rate (M=.55, SD=.16) than the short rate (M=.32, SD=.16). There was also a significant main effect of retention interval ($F(1,29)=31.54$, $\eta_p^2=.52$, $p<.001$), with higher performance following the short retention (M=.52, SD=.17) than the long retention (M=.35, SD=.15). There was also a significant main effect of type of test ($F(1,29)=37.54$, $\eta_p^2=.56$, $p<.001$), with higher performance on the item memory test (M=.51, SD=.14) than on the associative memory test (M=.36, SD=.16).

The three-way interaction between presentation rate, retention interval, and test just approached significance ($F(1,29)=4.19$, $\eta_p^2=.13$, $p=.05$). Follow-up two-way

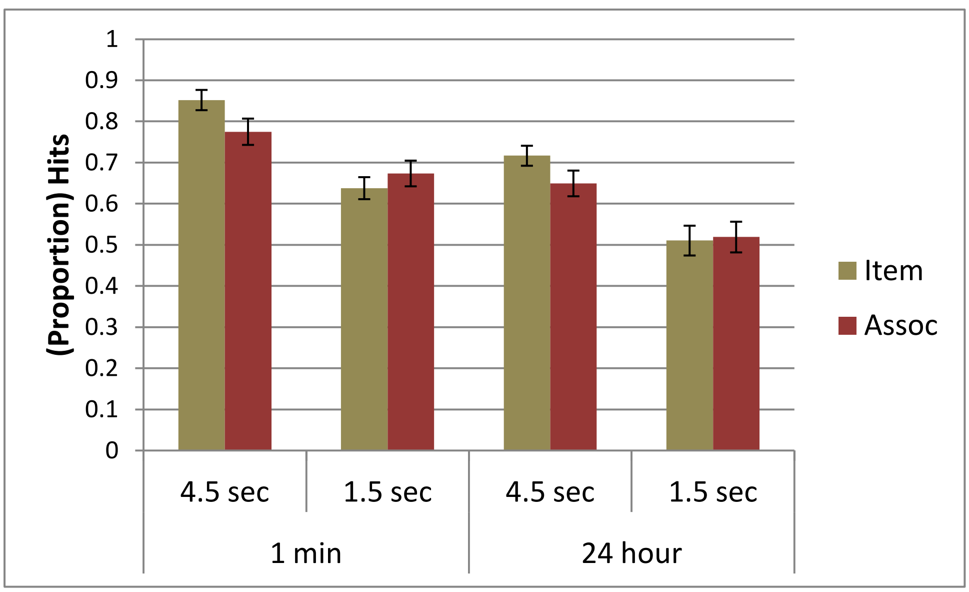
ANOVAs revealed a marginally significant interaction between presentation rate and test at the long retention interval ($F(1,29)=3.33$, $\eta_p^2=.10$, $p=.08$), but not at the short retention interval ($F(1,29)=.41$, $\eta_p^2=.01$, $p=.53$). This marginally significant interaction between rate and test at the long retention interval was in the opposite direction to the initial hypothesis, however. There was a significant interaction between retention interval and test at the long presentation rate ($F(1,29)=4.51$, $\eta_p^2=.14$, $p<.05$), but not at the short presentation rate ($F(1,29)=.77$, $\eta_p^2=.03$, $p=.39$). Follow-up t-tests on the interaction between retention and test at the long rate revealed a larger significant difference in associative test performance between the short retention (M=.59, SD=.26) and the long retention (M=.33, SD=.29) intervals ($t(29)=4.95$, $p<.001$) than in item test performance between the short retention (M=.70, SD=.20) and the long retention (M=.57, SD=.14) intervals ($t(29)=3.10$, $p<.01$), $t(29)=2.12$, $p<.05$.

Planned comparison ANOVAs revealed a significant interaction of test with the comparison of the long rate/long retention condition and the long rate/short retention condition ($F(1,29)=4.51$, $\eta_p^2=.14$, $p<.05$), but no significant interaction of test with the comparison of the short rate/short retention condition and the long rate/short retention condition ($F(1,39)=.41$, $\eta_p^2=.01$, $p=.53$), or of test and the comparison of the short rate/long retention condition and the long rate/short retention condition ($F(1,29)=.15$, $\eta_p^2=.005$, $p=.70$.

Proportion hits and proportion false alarms were also looked at separately. Examining proportion hits (see Figure 11), there were significant main effects of presentation rate ($F(1,29)=54.20$, $\eta_p^2=.65$, $p<.001$), with higher proportion hits for the long rate (M=.75, SD=.12) than the short rate (M=.59, SD=.13), and retention interval

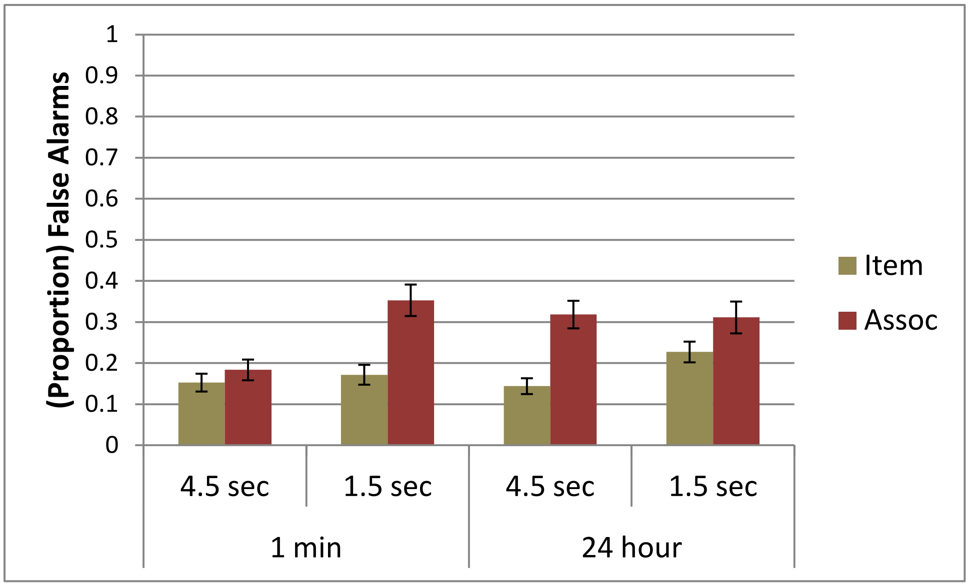
($F(1,29)=52.40$, $\eta_p^2=.64$, $p<.001$), with higher proportion hits following the short retention ($M=.74$, $SD=.10$) than the long retention ($M=.60$, $SD=.13$). But there was no significant main effect of type of test ($F(1,29)=2.73$, $\eta_p^2=.09$, $p=.11$), with proportion hits being similar on the item test ($M=.68$, $SD=.12$) and the associative test ($M=.65$, $SD=.11$). The only significant interaction was between presentation rate and type of test ($F(1,29)=9.15$, $\eta_p^2=.24$, $p<.01$). Follow-up t-tests revealed that even though there was a higher proportion of hits for the long rate ($M=.78$, $SD=.11$; $M=.71$, $SD=.15$) than the short rate ($M=.57$, $SD=.16$; $M=.60$, $SD=.13$) for both item ($t(29)=10.09$, $p<.001$) and associative memory tests ($t(29)=3.60$, $p<.01$), respectively, this difference was significantly larger for the item memory test ($t(29)=3.03$, $p<.01$).

Figure 11. Proportion Hits from Experiment 3



Examining proportion false alarms (see Figure 12), there were significant main effects of presentation rate ($F(1,29)=9.91$, $\eta_p^2=.26$, $p<.01$), with higher proportion false alarms for the short rate ($M=.27$, $SD=.12$) than the long rate ($M=.20$, $SD=.08$), and type of test ($F(1,29)=31.65$, $\eta_p^2=.52$, $p<.001$), with higher proportion false alarms on the associative test ($M=.29$, $SD=.11$) than the item test ($M=.17$, $SD=.09$). But there was no significant main effect of retention interval ($F(1,29)=2.66$, $\eta_p^2=.08$, $p=.11$), with proportion false alarms being similar following the long retention ($M=.25$, $SD=.09$) and the short retention ($M=.22$, $SD=.11$). The three-way interaction between presentation rate, retention interval, and type of test was significant ($F(1,36)=13.67$, $\eta_p^2=.32$, $p<.01$). Follow-up two-way ANOVAs revealed a significant interaction between presentation rate and test at the short retention interval ($F(1,29)=11.82$, $\eta_p^2=.29$, $p<.01$), but not at the long retention interval ($F(1,29)=2.07$, $\eta_p^2=.07$, $p=.16$). Follow-up t-tests on the interaction between rate and test at the short retention interval showed a significantly larger difference in associative test performance between the long rate ($M=.18$, $SD=.14$) and the short rate ($M=.35$, $SD=.21$) ($t(29)=4.42$, $p<.001$) than in item test performance between the long rate ($M=.15$, $SD=.12$) and the short rate ($M=.17$, $SD=.13$) ($t(29)=.99$, $p=.33$), $t(29)=3.44$, $p<.01$.

Figure 12. Proportion False Alarms from Experiment 3



There was also a significant interaction between retention interval and test at the long presentation rate ($F(1,29)=13.15$, $\eta_p^2=.31$, $p<.01$), but only a marginally significant interaction at the short presentation rate ($F(1,29)=4.07$, $\eta_p^2=.12$, $p=.053$). Follow-up t-tests on the interaction between retention and test at the long presentation rate showed a significantly larger difference in associative test performance between the short retention (M=.18, SD=.14) and the long retention (M=.32, SD=.18 intervals ($t(29)=3.98$, $p<.001$) than in item test performance between the short retention (M=.15, SD=.12) and the long retention (M=.14, SD=.11) intervals ($t(29)=.41$, $p=.69$), $t(29)=3.63$, $p<.01$.

Discussion

The results were similar to what was found in Experiment 2. Specifically, when looking at proportion false alarms, we were able to again show a bigger increase in the associative tests than in the items tests when either the presentation rate was shortened or the retention interval was lengthened. However, again similar to results from Experiment

2, this difference between associative and item tests was not larger when both manipulations were combined, but actually grew smaller, leading to the opposite 3-way interaction for the proportion false alarms (as well as for the proportion hits minus false alarms) that was expected.

Interestingly, these results still occurred even though we were able to effectively reduce floor effects. The repetition procedure added to Experiment 3 did improve overall memory performance, including in the short rate/long retention condition. This suggests that the lack of an associative memory deficit in that condition is not merely due to floor effects, as was hypothesized.

General Discussion

The age-related associative deficit hypothesis was suggested by Naveh-Benjamin (2000) in order to account for older adults' decline in episodic memory performance. This hypothesis states that older adults have difficulty in binding multiple items together in memory and also in later retrieving these bindings. A large amount of evidence exists to support this hypothesis (Old & Naveh-Benjamin, 2008).

Both the FL (specifically the pre-frontal cortex) and the MTL/H (specifically the hippocampus) have been implicated in mediating the associative deficit, through strategic and automatic binding deficits, respectively (Dennis et al., 2008; Glisky et al., 1995; Kan et al., 2007; Mitchell et al., 2000; Raz et al, 2005). The current study was an attempt to further elucidate how these underlying brain areas may be responsible for this deficit by independently manipulating each through the use of indirect behavioral measures thought to reflect their functioning. A simulated associative deficit in younger adults using these manipulations should provide clues as to how these brain areas work independently and in combination to cause older adults' associative deficit.

In Experiment 1, we compared younger adults' item vs. associative memory performance while manipulating the rate of presentation for each study and test event (6 seconds vs. 1.5 seconds) and the length of retention interval in between each study and test phase (one-minute vs. 10-minutes). Results indicated that while neither manipulation alone caused a simulated associative deficit, when the manipulations were combined there was a trend (marginally significant) towards an associative deficit. At first glance, these results seem to suggest that the associative deficit may not be caused by FL or MTL/H deficits independently, but only by their combined effects. However, the presentation rate manipulation did significantly increase false alarms in the associative test more so than in the item test, and no such difference was shown for the retention interval manipulation. As such, it appears that the trend towards an associative deficit in Experiment 1 is being driven almost entirely by the presentation rate manipulation. This pattern of results may be due to the retention interval manipulation being too weak, casuing a relatively small overall decline in performance.

By strengthening the retention interval manipulation (from 10-minutes to 24-hours) in Experiment 2, results showed a trend towards an associative deficit when either presentation rate or retention interval were manipulated on their own (specifically in the increase in associative false alarms, as hits minus false alarms data still did not reach significance). Interestingly, the combination of both manipulations did not cause an additive effect to the simulated associative defict, but actually caused less of a deficit.

This was driven by an increase in item false alarms relative to associative false alarms for this condition.

It is unclear why the presentation rate manipulation at the one-minute retention interval yielded a larger differential in test performance in Experiment 2 than in Experiment 1, because these conditions were kept the same between both experiments. The only aspects that changed were the number of study-test blocks and the number of trials in each. This larger differential in test performance was driven entirely by proportion hits and not by proportion false alarms, however. Whereas in Experiment 1 hit rates were slightly higher for the item vs. associative tests in both presentation rate conditions, in Experiment 2 hit rates were slightly lower for the item vs. associative tests in both presentation rate conditions.

Another potential issue with Experiment 2 was that by strengthening the retention interval manipulation (by lengthening the interval), floor effects may have been introduced in the short rate/long retention interval condition. Any increased associative deficit in that condition, therefore, may have been attenuated by performance levels being too low (specifically in the item test). Experiment 3 was able to successfully reduce these floor effects by increasing overall performance through the use of repetition at study. However, even without floor effects, the pattern of results remained similar to Experiment 2.

So the question still remains of how to reconcile the different patterns seen in Experiment 1 vs. Experiments 2 and 3. Whereas Experiment 1 suggests the combination of FL and MTL/H deficits contributes to the associative deficit, Experiments 2 and 3 seem to suggest somewhat the opposite—that either FL or MTL/H deficits contribute equally and independently, but not in combination. Since floor effects have been ruled out in Experiment 3, we think the answer lies in the false alarm data.

As mentioned earlier, the age-related associative deficit is driven mostly by an increase in associative false alarms as opposed to a decrease in associative hits (Kilb & Naveh-Benjamin, 2011; Naveh-Benjamin et al., 2009). Similar patterns have been shown in the current study in false alarms when presentation rate is manipulated (Experiments 1, 2, and 3) or when retention interval is manipulated (using the stronger manipulation, as in Experiments 2 and 3). However, when these two manipulations are combined together, even though there is still an increase in associative false alarms, in Experiments 2 and 3 there also is a larger increase in item false alarms. The effect of this is to cause the difference between item and associative test peformance to be minimized. In Experiment 1 this was not the case because the retention interval manipulation was not strong enough. So in Experiments 2 and 3, either the combination of the two manipulations do not cause a large decline in associative memory or the problem lies in the strength of the retention interval manipulation and its combination with a short 1.5 second presentation rate creating too strong a manipulation. Such a combination might have caused item false alarms to be just as negatively affected as associative false alarms. Such a possibility could account for the discrepancies seen between Experiments 1 and 2 and 3. Further research would be needed to test whether a retention interval somewhere between 10 minutes and 24 hours would be enough to cause an associative deficit by itself, but not be too strong to cause lower levels of performance when combined with short presentation rates.

The current study purposely confounded the presentation rate at study and test by combining them to form a stronger manipulation of presenation rate. Since evidence from this study suggets that presentation rate does mediate the associative deficit (at least in part), future studies would be needed to look at the effects of encoding and retrieval separately in order to break down this effect even further.

Further research would also be needed to confirm that the behavioral manipulations used in the current study do indeed indirectly affect the FL and MTL/H, as was discussed in the introduction. It is possible that our manipulations may reflect other underlying processes and brain structures that we have not accounted. However, the behavioral results—especially the false alarm scores—are in line with what would be expected given proper behavioral manipulations. One way to test this would be to administer a similar behavioral paradigm while utilizing fMRI technology to look at the concurrent patterns in neurological activity. There were some methodological concerns that need to be mentioned, as well. The presentation rate manipulation was identical in Experiments 1 and 2, yet the behavioral results were different for both the baseline condition and the short rate/short retention condition. Whereas item memory performance was higher in both conditions in Experiment 2 relative to Experiment 1, associative memory performance was lower in both conditions in Experiment 2 relative to Experiment 1. This led to a larger associative deficit in both of these conditions in Experiment 2 relative to Experiment 1. The reason for these differing results between the first two experiments remains unclear. Although the presentation rate and retention interval were identical between the first two experiments, the number of study-test blocks and the amount of stimuli in each was different. It does not seem reasonable that this change in procedure would both improve item memory while also decreasing associative memory. The more likely explanation is that it was merely a reflection of sampling differences due to different sets of participants used in the two experiments.

Other methodological issues included the possibility that the long presentation rate of 6 seconds was actually too long. Several participants claimed that they lost focus during the long rate conditions and did not use the full 6 seconds at both study and test. Reaction time measures confirmed that participants were responding, on average, well before the 6 second deadline during test trials. This is one reason why the long rate condition was changed to 4.5 seconds for Experiment 3.

One final methodological issue concerns the stimuli used. The pictures of faces, although taken from a standardized database, were not culturally diverse. All images were of white, European males or females, and a couple participants mentioned this lack of diversity during the post-test questionnaire process. However, across all three experiments, the faces were remembered slightly better than the scenes, so this lack of diversity did not seem to negatively affect performance (at least not to a disproportionate level).

In conclusion, relating the observed behavioral effects to the underlying brain structures presumably involved, the current study provides support for the notion that deficits in FL and MTL/H structures are equally involved in mediating the associative deficit (especially via affecting false alarm rates), yet whether these effects are additive (i.e. Experiment 1), involve only specific combinations of conditions (i.e. Experiments 2 and 3), or interactive, still remains unclear and is in need of future research.

By effectively simulating the associative memory deficit in younger adults using manipulations designed to represent both FL and MTL/H deficits, the current study is an important step in providing a theoretical framework for better understanding the underlying causes of associative memory decline in older adults.

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