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The impact of level of education on age-related deficits in associative memory: Behavioral and neuropsychological perspectives

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ABSTRACT

Older adults have difficulty forming associations and binding distinct item components despite mostly preserved item memory potentially because they rely on more automatic, rather than strategic, processing when attempting to form, store, and retrieve associations from memory. An intriguing possibility is that older adults with greater access to strategic processes (e.g., those with a high level of education) may be less susceptible to age-related associative memory deficits. Two experiments assessed the degree to which a high level of education provides an effective dose of cognitive reserve (CR), potentially preserving associative memory. Standard younger and older adults' item and associative memory performance was compared to older adults who had attained a high level of education (mostly doctoral degrees). In both experiments (Experiment 1: person–action pairs; Experiment 2: unrelated word pairs), consistent evidence was found that older adults, regardless of the level of education, exhibited an age-related associative memory deficit relative to younger adults. Interestingly, neuropsychological assessment of both older adult groups revealed greater frontal lobe, but not enhanced medial temporal lobe, functioning in the highly educated. As such, although the highly educated older adults exhibited greater frontal lobe functioning than the standard older adults, this did not aid in the reduction of the age-related associative memory deficit.

1. Introduction

Aging is accompanied by changes in vital cognitive abilities necessary for activities in everyday life. However, a variety of relevant factors contribute to significant variability in the expression of the degree of decline in certain cognitive processes (e.g., health: Aine, et al., 2011; education: Shimamura, Berry, Mangels, Rustin, & Jurica, 1995; Zahodne et al., 2011; genetic factors: Papenberg, Salami, Persson, Lindenberger, & Bäckman, 2015; neural correlates: MacDonald, Li, &

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Bäckman, 2009). Moreover, aging is associated with brain-related changes such as declines in gray matter volume in cortical and subcortical regions (Sowell, Thompson, & Toga, 2004; Terry, DeTeresa, & Hansen, 1987). However, there is a great deal of variability within older adults with respect to not only which brain regions are impacted but also how quickly these changes occur (Raz, Ghisletta, Rodrigue, Kennedy, & Lindenberger, 2010). These sources of variability within aging populations present a novel challenge for cognitive aging research.

One theoretical perspective attempting to account for variability in cognitive performance within older adults proposes a hypothetical *cognitive reserve* (CR) (Stern, 2002). CR refers to the observation that despite the inevitability of age-related changes within the brain, certain individuals maintain high levels of cognitive performance by accessing intact neurocognitive processes or by recruiting compensatory processes (Barulli & Stern, 2013). *Compensation* involves the recruitment of neural networks that are distinct from the primary network underlying a given cognitive process in service of accomplishing a particular task. Thus, if the neural regions underlying a given cognitive process are not operating effectively, the recruitment of alternative networks may aid in the preservation of cognitive functioning (Barulli & Stern, 2013). Indeed, age-related individual differences in cognitive performance are associated with patterns of neural activation indicative of compensatory processing. For instance, low and high performing older adults exhibit distinct patterns of neural activity during associative memory tasks (e.g., binding unrelated word pairs, Cabeza, Anderson, Locantore, & McIntosh, 2002). Interestingly, while the low performing older adults recruit cortical regions similar to younger adults (e.g., right prefrontal cortex, PFC), they did so ineffectively. High performing older adults, however, recruit PFC regions bilaterally (e.g., left and right PFC), indicating the ability to enlist compensatory mechanisms in service of the memory task (Cabeza et al., 2002).

Moreover, CR models acknowledge that changes in cognitive functioning depend, to some degree, on previous experience across the lifespan. While a number of factors collectively comprise life course experience, one factor that is typically measured in cognitive aging studies is level of education. It is possible that older adults who have completed a greater number of years of formal education during their lifetime may comprise a distinct subgroup of the aging population who exhibit higher or more efficient levels of CR (e.g., Saliasi, Geerligs, Dalenberg, Lorist, & Maurits, 2015). It is possible that a high level of education may help to preserve cognitive function given that diagnoses of common age-related pathologies (e.g., dementia) tend to occur later in life for highly educated older adults compared to those with lower levels of education (Amieva et al., 2014; Bennett et al., 2003; Christensen, Doblhammer, Rau, & Vaupel, 2009; Karlamangla et al., 2009; Yaffe et al., 2009).

Empirically, highly educated older adults surpass those with relatively lower levels of education on certain measures of cognitive functioning. For instance, Shimamura et al. (1995) examined cognitive functioning, using several measures of cognitive performance, in young, middle, and older aged active professors compared to two control groups of standard younger and older adults with similar levels of education. Increased age was generally associated with decreased processing speed, which was most pronounced for standard older adults followed by older professors and then the middle-aged and younger age groups. In comparison to all younger and middle-aged groups, working memory (WM) ability and prose recall, however, were preserved in the older professors relative to the standard older adults (Shimamura et al., 1995). Finally, of primary interest to the current work, level of education, compared to other demographic factors (e.g., race, gender) has been shown to be associated with older adults' performance on measures of episodic memory (e.g., Weschler Memory Scale-Revised Logical Memory), with higher levels of education conceivably providing a proxy-measure of CR (Jefferson et al., 2011).

1.1. *Age-related declines in item and associative memory*

Importantly, age-related declines in episodic memory are prevalent in the cognitive aging literature (see Craik & Bialystok, 2006; Old & Naveh-Benjamin, 2008a; Zacks, Hasher, & Li, 2000). Viewed within the context of the source monitoring framework (e.g., Johnson, Hashroudi, & Lindsay, 1993; Johnson & Raye, 1981; Mitchell & Johnson, 2009), associative (i.e., binding) processes may be adversely impacted in aging populations. Indeed, older adults have trouble forming associations between components within episodic memory (Chalfonte & Johnson, 1996). Moreover, the associative deficit hypothesis (ADH) suggests that one reason for the age-related declines in episodic memory is that older compared to younger adults have difficulty encoding and retrieving associations between distinct components of an episode while memory for the individual components remains largely intact (Naveh-Benjamin, 2000). In most associative memory task paradigms, stimulus pairs (e.g., face–name pairs, word–word pairs) are originally presented during a study phase and followed, after a delay, by two separate tests. During item tests, participants must indicate whether they have seen an individual component (e.g., a face, a name) during the study phase. In contrast, associative tests involve the presentation of a stimulus pair, which either remains intact (e.g., same face–name pair as shown during the previous study phase) or is recombined between two components that appeared during the study phase but were not originally presented together. Older, relative to younger, adults typically have greater difficulty with the associative memory compared to item memory test events. In support of the ADH, a number of empirical findings from behavioral experiments that have examined older adults with an average level of education have replicated the age-related associative deficit using various types of distinct components (e.g., unrelated word pairs, face–name pairs, face–scene pairs, picture pairs, person–action pairs: Bastin & Van der Linden, 2005; Castel & Craik, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Old & Naveh-Benjamin, 2008b; for a meta-analytic review see Old & Naveh-Benjamin, 2008a).

Moreover, findings from experiments employing standardized neuropsychological tests indicate dissociable differences in older adults' item and associative memory contingent upon level of frontal lobe and medial temporal lobe

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functioning (e.g., high, low). For instance, differences in frontal lobe function seem to underscore variability in associative memory but not item memory performance, with standard high-functioning older adults outperforming low-functioning older adults (Glisky, Polster, & Routhieaux, 1995). Importantly, strategic processing may rely on structures within the frontal lobes, as evident by an impoverished ability to engage such processes after frontal lesions (see Moscovitch, 1992; Shimamura, 1994). Indeed, patients with frontal lobe lesions have difficulty using organizational strategies to aid memory processes in an effective manner (Eslinger & Grattan, 1994; Gershberg & Shimamura, 1995).

As such, age-related declines within frontal regions may, in part, weaken older adults' access to strategic processes, requiring them to rely on automatic processes during associative memory tasks. This could result in decreased strategy use during both encoding and retrieval. Such a reduction in strategic processing may result in less effective binding of the episodic components during encoding (e.g., relating a name to a face), and, in addition, may lead to increased susceptibility to item familiarity during attempted retrieval of a given association (e.g., resulting in erroneously endorsing a face–name pair due to familiarity with the name component; Naveh-Benjamin, Kilb, & Reedy, 2004). The claim that older adults may be less proficient in using strategic processes during associative memory tasks is also supported by findings which indicate that providing instructions regarding the effective use of strategies does benefit older adults' associative memory performance, decreasing the age-related deficit (Naveh-Benjamin, Brav, & Levy, 2007).

Intriguingly, older adults with a high level of education (e.g., doctoral degrees), who potentially have maintained a higher level of frontal lobe functioning may be able to use strategies without additional assistance given their frequent engagement in forming and integrating newly learned associations into an existing knowledge structure (Shimamura et al., 1995). Supporting the presumed relationship between declines in frontal lobe function, decreased strategy use, and age-related declines in associative memory (e.g., word-stem cued-recall task), there are indications that performance varies with level of education such that the smallest performance declines, relative to younger adult controls, are shown for older adults with higher compared to those with lower levels of education (Angel, Fay, Bouazzaoui, Baudouin, & Isingrini, 2010).

However, a more nuanced pattern of results was revealed in the study by Shimamura et al. (1995), which indicates that while highly educated older adults (e.g., college professors) outperform standard older adults on tasks involving paired-associate learning (i.e., cued-recall of face–face or name–name pairs), both of these older adult groups exhibit performance declines relative to the standard younger adult control group, with the largest declines exhibited by the standard older adults (Shimamura et al., 1995). As such, education may mediate the magnitude of age-related deficits in certain measures of cognitive functioning, including episodic memory (e.g., cued-recall), but does not seem to completely alleviate performance differences evident between younger and older adults.

Importantly, both the study by Shimamura et al. (1995), which used a paired-associates task, and that of Angel et al. (2010), which used a cued-recall task, did not use separate measures of item and associative memory performance, and, thus, could not carry out an independent assessment of differential associative memory decline. As such, performance on paired-associates and cued-recall tasks may potentially be driven by both associative memory (e.g., remembering the A–B association) and item memory (e.g., retrieval of component-B when presented with component-A). Thus, it remains unclear whether, and to what extent, associative memory, relative to item memory, is protected from aging due to a high level of education.

If highly educated older adults do exhibit higher levels of frontal lobe functioning and, consequently, are better able to engage in strategic processes compared to standard older adults, it is possible that they may be better able to form, maintain, and retrieve associations within episodic memory. In turn, highly educated older adults may be less susceptible to age-related declines in associative memory, which are prevalent in samples from the aging population typically examined in aging studies.

1.2. *Current experiments*

The main goal of the current experiments relates to determining whether or not a high level of education aids in the preservation of older adults' ability to form, maintain, and retrieve associations between distinct item components within episodic memory. In Experiment 1, standard younger adults, standard older adults, and highly educated older adults were tested on their ability to remember videos of people performing various actions in an item and associative memory test format. In Experiment 2, new samples of standard younger adults, standard older adults, and highly educated older adults were tested on their item and associative memory for unrelated word pairs. Two distinct types of stimulus materials were used for the purpose of examining associative memory processes when the binding of dynamic and intrinsic visual components (Experiment 1; item–context binding) compared to binding of aurally presented, unrelated, distinct components (Experiment 2; item–item binding) was required. The rationale for assessing these unique stimulus materials and presentation formats relates to an attempt to generalize notable findings regarding age-related differences as a function of level of education across both the visual and auditory/verbal modalities.

In both experiments, an overarching prediction involves the expectation of an age-related associative memory deficit when comparing younger and standard older adults. In essence, standard older adults are expected to have disproportionately lower associative memory performance in comparison to younger adults despite relatively intact item memory performance. Second, with respect to level of education, however, two potentially distinct predictions are warranted. If level of education does indeed aid in the preservation of associative memory, the age-related associative deficit in highly educated older adults may be partially attenuated or, perhaps, absent completely when directly compared to associative memory performance in standard older adults. In contrast, the presence and magnitude of the age-related associative memory deficit may be similar or equal for standard and highly educated older adults, providing an example

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of pervasive cognitive decline that permeates even highly educated older adults. Additionally, in both experiments we examined medial temporal lobe and frontal lobe functioning in both older adult subgroups using nine standardized neuropsychological tests (similar to Glisky et al., 1995). We might expect similar medial temporal lobe but not frontal lobe functioning between standard older and highly educated older adults, given that PFC, but not MTL, regions have been shown to mediate inter-individual differences within older adults' associative memory performance (Becker et al., 2015).

2. Experiment 1

2.1. Methods

2.1.1. Participants

Participants (see Table 1) were 33 older adults (10 females; age range = 65–82, $M = 72.55$, $SD = 6.18$) most of whom had attained a doctoral degree (years of formal education: $M = 20.48$, $SD = 1.25$, range 19–26 years of education), 44 older adults without advanced degrees (33 females; age range = 65–81, $M = 72.91$, $SD = 4.94$; years of formal education: $M = 14.39$, $SD = 1.82$, range 12–18 years of education, which is similar to other studies examining item and associative memory) and 42 younger adults (25 females; age range = 18–23, $M = 20.17$, $SD = 2.19$; education: $M = 13.62$, $SD = 1.40$, range = 12–16 years of education). Both the highly educated older adults and the standard older adults resided in the community, were pre-screened[1] regarding standard exclusion criteria (e.g., none had suffered traumatic brain injury, open head injury, substance abuse, stroke, mild cognitive impairment, dementia, Parkinson's Disease, or any other memory impairments), reported no serious physical or mental health issues, and were compensated $15 per session for their participation. Younger adults were undergraduate students from introduction to psychology courses at the University of Missouri, who participated in exchange for course-related credit. All participants provided informed consent and all protocols were approved by the institutional review board at the University of Missouri. There was a significant difference in level of education between the three groups of participants, $F(2, 116) = 215.33$, $p < .001$. Bonferroni-corrected post-hoc comparisons revealed a non-significant difference in years of education between the younger and standard older adults ($p = .07$). However, the older adults with advanced degrees had significantly more years of education compared to both the younger and standard older adults (both p's $< .001$).

Table 1 – Demographic information for Experiment 1 and Experiment 2.

Experiment	N	Proportion (female)	Age (years)	Education (years)
Experiment 1				
Younger	42	.60	20.17 (2.19)	13.62 (1.40)
Standard older adults	44	.75	72.91 (4.94)	14.39 (1.82)
Highly educated older adults	33	.30	72.55 (6.18)	20.48 (1.25)
Experiment 2				
Younger	60	.50	18.80 (1.01)	12.36 (.76)
Standard older adults	52	.67	72.50 (5.28)	14.68 (1.88)
Highly educated older adults	43	.43	73.05 (6.70)	20.98 (1.71)

Note. The values for age and education depict means (standard deviations).

2.1.2. Stimulus materials

Stimuli consisted of 75 video clips (5 sec each) depicting people (ages 18–80, half male, half female) performing various actions (e.g., folding a towel, putting flowers in a vase) described previously (Old & Naveh-Benjamin, 2008b). Each action involved the manipulation of distinct object by an individual person. Five of the 75 person–action video clips were used as practice study video clips.[2]

Based on 64 of the remaining 70 person–action study clips (6 of these clips were not tested, as they were used as buffers for primacy and recency effects), item component test clips depicting either an individual person sitting still or an individual action being performed by a pair of hands (no face was visible) were created. During the item component test blocks, there were 14 person-only test clips and 14 action-only test clips (7 “old” targets, 7 “new” distractors), resulting in 14 “old” and 14 “new” item tests total across the two item test blocks. For the associative test clips, person–action pairs were either displayed intact (9 “intact” targets; same person performing same action) or were recombined (9 “recombined” distractors; a person from the study phase performing an action that had been performed by a different actor). Associative test distractor clips included actors that were replaced by actors of the same gender and age group. Video clips in each test appeared for 5 sec each. The participant could make their recognition judgment response using the keyboard (using keys labeled “old” and “new”) at any time during this 5-second interval while each test clip was playing. Each 5-second test clip was immediately followed by a 2-second interstimulus-interval (ISI). In both the study phase and in each of the test conditions, clip presentation order was randomized. Note that a given person or action appeared in only one of the 3 tests.

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[1] Mini-mental status examination (MMSE) scores were obtained for only a subset of the older adult participants from each group [standard older adults: $N = 21$, $M = 28.6$; highly educated older adults: $N = 7$, $M = 29.0$; $t(25) = 1.67$, $p = .11$]. Notably, the average MMSE scores obtained from these older adults were well above the standard cut-off score (i.e., 24) suggesting that the current older adult groups exhibited normal cognition.

[2] Of these 5 clips, 3 corresponded to associative practice test video clips (1 person–action clip remained intact, 1 was recombined across the other 2 person–action clips). Of the remaining 2 practice study clips individual components were sampled from these person–action clips and corresponded to the “target” person and action practice tests (e.g., a person or action from one of the original person–action practice-study clips). In addition, 2 “new” clips, (1 person and 1 action “distractor” clip) were presented as practice test clips. As such, there were 2 (1 target, 1 distractor) practice test clips presented to participants per test condition (person, action, associative).

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2.1.3. Procedure

The experiment was carried out across two separate sessions over two consecutive days. On Day 1 participants received instructions that they would view video clips of people performing actions and that they should attend to the person, the action, and the fact that a given person was performing a particular action as they would be subsequently tested on individual people, actions, and person–action pairings. During the study phase 70 video clips were presented to participants with a 30 sec break after half of the clips had been presented. Following the study phase, participants performed a crossword puzzle for 5 min prior to the start of one of three separate test blocks (with test block order counterbalanced across participants in each age group). Participants were instructed that in the first type of test, the person-only test, each clip would consist of a single person sitting still, that in the second type of test, action-only test, each clip would consist of a pair of hands performing an action (no face or personal identifying features appeared), and finally that in the third type of test, the person–action associative test, that a person would be performing an action, but that the same person may not have performed the same action as originally performed at study. Test block order, with either the two item tests occurring first (i.e., person only test, action only test, also counterbalanced) or the associative test occurring first, was counterbalanced across participants within each group. Participants were also informed that half of the clips would be targets (i.e., “old”) while the other half would be distractors (i.e., “new”) and were instructed to make their recognition responses using the keyboard by pressing keys labeled “old” if they remembered seeing the item (person in the person-only test block or action in the action-only test block) or intact associative pair during the study phase and “new” if they did not remember seeing the item presented at test or if the associative pair had been recombined from study to test. Participants viewed practice study and test clips to ensure comprehension of the task procedures. 32 of the person–action clips corresponded to the test stimuli used on Day 1. The Day 1 session took approximately 50–60 min and at the end of it participants were told to return the next day for the second session without mention of a subsequent memory test.

On Day 2, no study phase was presented and participants returned to complete the same type of three tests (counterbalanced across participants with either the item tests occurring first: person only test, action only test or the associative test occurring first) that included 32 of the test items and pairs from the clips presented and not tested on during the Day 1 study phase (i.e., 32 of the study pairs presented on Day 1 were tested in either an item or associative memory test format on Day 2). Participants were not informed ahead of time regarding the purpose of the second session.

After completing the three tests (which took approximately 10 min), a trained experimenter administered nine neuropsychological tests, similar to those that have been used previously (e.g., Glisky et al., 1995; Glisky, Rubin, & Davidson, 2001), to the older adult participants to assess frontal lobe function (five tests) or medial temporal lobe function (four tests) within the brain. First, the frontal lobe measures of standardized neuropsychological tests, including (1) the number of categories attained on the modified Wisconsin Card Sorting Task (WCST; Hart, Kwentus, Wade, & Taylor, 1988), (2) the total number of words generated on the Controlled Oral Word Association Test (FAS test, Benton & Hamsher, 1976), (3) Mental Arithmetic from the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), (4) Mental Control from the Wechsler Memory Scale-Revised (WMS-R; Wechsler, 1987), and (5) Backward Digit Span from the WMS-R, were administered. Next, the medial temporal lobe function set of standardized neuropsychological tests included Logical Memory I: Parts A and B (immediate recall) and Logical Memory II: Parts A and B (delayed recall), Family Pictures I (free and cued recall) and Family Pictures II (delayed free and cued recall) from the Wechsler Memory Scale-Third Edition (WMS-III, Wechsler, 1997). The order of these four tests included the Logical Memory I (A & B), Family Pictures I, followed by a 30-minute delay, and, finally, Logical Memory II (A & B) and Family Pictures II. The Day 2 session took approximately 90 min to complete.

2.2. Results

2.2.1. Item and associative memory performance

We measured overall response accuracy corresponding to performance during the Day 1 & Day 2 sessions by computing separately the proportion of hits and the proportion of false alarms and then subtracting the proportion of false alarms from the proportion of hits (henceforth, corrected recognition) in each experimental condition for each participant in each age group (see Fig. 1 and Table 2). As is common in the associative memory and aging literature, we averaged performance in the person and action item test conditions to yield composite item performance values. Composite item performance values were examined given that the contrast of primary interest was related to whether or not differential levels of performance were evident between younger and older adults when tested on *either* of the individual item components relative to the associations between these components. Additionally, we averaged performance across both experimental sessions (i.e., Day 1, Day 2) for each participant in both the composite item test and associative test conditions using the corrected recognition values from Day 1 & Day 2.

First, we examined whether an age-related deficit was present, comparing performance across all three groups. The corrected recognition values were submitted to a 3 × 2 repeated-measures analysis of variance (ANOVA) including the between-subjects factor of age (younger, standard older, highly educated older adults) and the within-subjects factors of memory test type (item, associative).

There was a main effect of age, $F(2, 116) = 15.52$, $p < .001$, $\eta_p^2 = .21$, confirming that younger adults ($M = .53$, $SD = .14$) performed with greater accuracy compared to both the standard older ($M = .39$, $SD = .13$, $p < .001$) and the highly educated older adults ($M = .39$, $SD = .13$, $p < .001$). The overall difference in performance between the two older adult groups was not significant ($p = .90$). Additionally, there was a main effect of test, $F(1, 116) = 17.79$ $p < .001$, $\eta_p^2 = .13$, indicating greater accuracy during tests of item ($M = .48$, $SD = .08$) compared to associative ($M = .40$, $SD = .12$) memory. Finally, there was a

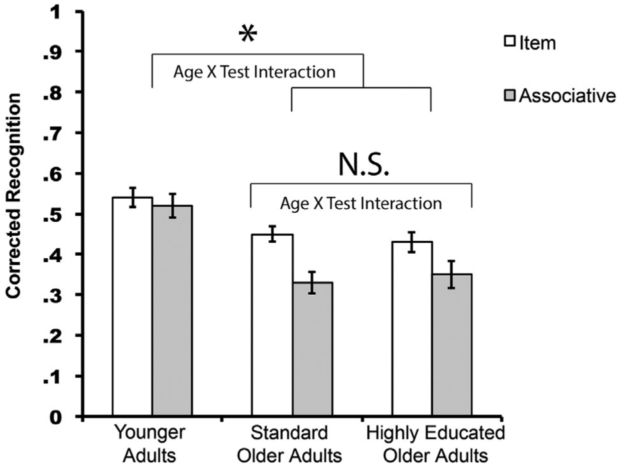

Fig. 1 – Experiment 1 – Results depicting the corrected recognition (i.e., proportion hits minus proportion false alarms) for each subgroup for each memory test condition: The abscissa depicts the younger, standard older, and highly educated older adult subgroups while their levels of performance in both item and associative recognition memory (averaged Day 1 & Day 2 corrected recognition) is plotted along the ordinate. Error bars represent the standard error of the mean in each test condition. Asterisks denote a significant age by test interaction between the younger adults and all older adults ($p < .05$). N.S. denotes a non-significant age by test interaction between the older adult groups.

significant interaction between the factors of age and test, $F(2, 116) = 3.36$, $p = .04$, $\eta_p^2 = .06$, suggesting the presence of an age-related associative memory deficit.

To assess whether there was an overall age-related associative memory deficit, we combined the two older adults groups into a single older adult group prior to conducting follow-up analyses on the significant interaction. A follow-up 2 (younger adults, all older adults) × 2 (item, associative) ANOVA indicated a significant age by test interaction, $F(1, 117) = 5.50$, $p = .02$, $\eta_p^2 = .05$. Follow-up paired samples t-tests[3] indicated no difference between item ($M = .54$, $SD = .15$) and associative ($M = .52$, $SD = .19$) memory test performance for the younger adults, $t(41) = .85$, $p = .40$. However, for the older adults, associative memory performance ($M = .34$, $SD = .19$) was significantly lower than item memory ($M = .44$, $SD = .13$) performance, $t(76) = 4.39$, $p = .001$. Importantly, a follow-up 2 × 2 ANOVA comparing performance in the two groups of older adults revealed no significant interaction between group and test $F(1, 75) = .99$, $p = .32$, further confirming that the age-related associative memory deficit did not vary with level of education (see Fig. 1).

Table 2 – Experiment 1: Mean corrected recognition (i.e., proportion hits minus proportion false alarms) values (with standard deviations) for each experimental condition for younger and older adults.

	Younger adults	Standard older adults	Highly educated older adults
Proportion hits			
Item Day 1	.77 (.12)	.70 (.13)	.71 (.17)
Item Day 2	.62 (.10)	.53 (.15)	.53 (.16)
Item Day 1 & 2	.70 (.09)	.61 (.11)	.62 (.13)
Assoc Day 1	.87 (.12)	.83 (.20)	.82 (.16)
Assoc Day 2	.76 (.20)	.69 (.19)	.70 (.19)
Assoc Day 1 & 2	.82 (.13)	.76 (.16)	.76 (.15)
Proportion false alarms			
Item Day 1	.14 (.13)	.14 (.12)	.14 (.12)
Item Day 2	.16 (.13)	.18 (.13)	.24 (.14)
Item Day 1 & 2	.16 (.10)	.16 (.10)	.19 (.11)
Assoc Day 1	.23 (.17)	.39 (.21)	.37 (.21)
Assoc Day 2	.36 (.15)	.47 (.18)	.45 (.17)
Assoc Day 1 & 2	.29 (.11)	.43 (.14)	.41 (.15)
Corrected recognition			
Item Day 1	.63 (.20)	.55 (.16)	.56 (.19)
Item Day 2	.46 (.17)	.36 (.17)	.29 (.17)
Item Day 1 & 2	.54 (.15)	.45 (.12)	.43 (.14)
Assoc Day 1	.65 (.22)	.44 (.26)	.45 (.27)
Assoc Day 2	.40 (.25)	.22 (.21)	.25 (.21)
Assoc Day 1 & 2	.52 (.19)	.33 (.18)	.35 (.19)

2.2.2. *Neuropsychological test performance*

To examine performance on the nine neuropsychological tests administered to both the standard and highly educated older adults (see Table 3 for means, standard deviations, factor loadings, eigenvalues, and percentage variance explained), we followed a similar factor analytic strategy previously employed by Glisky et al. (1995). In general, we were interested in potential differences in frontal and medial temporal lobe functioning between the standard and highly educated older adults independent of chronological age. As such, variance related to age was removed from each of the eight[4] test scores included in the factor analysis by first conducting linear regression analyses using the scores on each test as a dependent variable and the age of each older adult participant ($N = 77$) as an independent variable. Studentized residual scores resulting from these regression analyses were used to conduct an exploratory factor analysis using maximum likelihood estimation as the extraction method. Kaiser-Meyer-Olkin's measure of sampling adequacy was low, but sufficient (.61) and Bartlett's test of sphericity was significant, $\chi^2_{\text{approx}}(28) = 317.44$, $p < .001$. Factors with eigenvalues greater than 1 were extracted and subjected to oblique rotation, revealing that the variance within the eight neuropsychological test scores included in the factor analysis loaded onto three distinct factors. Of these factors, one factor loaded onto the Family Pictures I

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[3] An independent samples t-test indicated that the difference between younger and older adults was significant in the comparison of item (younger: $M = .54$, $SD = .15$; older: $M = .44$, $SD = .13$) memory, $t(117) = 3.83$, $p < .001$. However, this difference was relatively larger in the between-age groups comparison of associative (younger: $M = .52$, $SD = .15$; older: $M = .34$, $SD = .13$) memory, $t(117) = 5.16$, $p < .001$.

[4] The results from the number of categories achieved on the WCST revealed very little variability across all of the older adult participants (median score = 6 categories out of 6 total), resulting in an extremely negatively skewed distribution of raw scores. As such, the residual scores corresponding to this test were not included in the factor analysis.

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Table 3 – Experiment 1: Neuropsychological test raw score means and loadings extracted from oblique rotation of the maximum likelihood estimation factor analysis.

Test	Raw scores Mean (SD)	Factor 1 MTL-General	Factor 2 MTL-Verbal	Factor 3 Frontal Lobe
Logical Memory I	43.26 (9.82)	–	.83	–
Family Pictures I	37.14 (11.24)	.98	–	–
Logical Memory II	24.92 (7.90)	–	.95	–
Family Pictures II	36.73 (11.53)	.92	–	–
Wisconsin Card Sorting Task	4.53 (1.93)	–	–	–
Controlled Oral Word Association	37.40 (11.18)	–	–	.49
Mental Arithmetic	12.66 (4.01)	–	–	.69
Mental Control	24.77 (5.60)	–	–	.72
Digit Span (backwards)	6.68 (2.19)	–	–	.38
Eigenvalue		2.24	1.62	1.15
Variance (%)		28.01	20.20	14.38

and Family Pictures II, likely explaining variance attributable to MTL functioning for both visual and verbal memory content, given that the Family Pictures task relies heavily on both visual and auditory-verbal cognitive processes (henceforth, MTL-General factor; see Chapin, Busch, Naugle, & Najm, 2009; Dulay et al., 2002). A second factor loaded onto the Logical Memory I and Logical Memory II tests. Given that no visual stimuli are presented and the stories were read, aloud, to the participant by the experimenter, these two tests likely explain variance attributable to MTL functioning for solely verbal memory content (henceforth, MTL-Verbal factor; Chapin et al., 2009). The third and final factor loaded onto the FAS, Mental Arithmetic, Mental Control, and Backward Digit Span tests. Consistent with the results of Glisky et al. (1995), these tests likely collectively account for variance associated with frontal lobe functioning (henceforth, Frontal factor).

Using this three-factor solution, factor scores for each participant were computed (using Bartlett's method). Standardized scores for each participant (i.e., studentized residuals) corresponding to each of the eight neuropsychological tests were multiplied by the corresponding standardized scoring coefficient for each test obtained from the resulting factor score coefficient matrix for each factor and summed to create a weighted factor score representing a given participant's relative performance on each factor (negative values = below the mean; positive values = above the mean). To examine differences in neuropsychological functioning between the standard older and highly educated older adults, we submitted the weighted factor scores for the participants from each of these groups corresponding to each of the three separate factors to independent samples *t*-tests. No significant difference between the standard older ($M = .01$, $SD = .92$) and highly educated older adults ($M = -.02$, $SD = 1.11$) was observed between the weighted factor scores corresponding to the MTL-General factor, $t(75) = .15$, $p = .88$. Similarly, there was no difference between the factor scores for the standard older ($M = -.12$, $SD = 1.09$) and highly educated older adults ($M = .16$, $SD = .93$) corresponding to the MTL-Verbal factor, $t(75) = 1.19$, $p = .24$. However, the between-groups comparison of the weighted factor scores corresponding to the Frontal factor indicated a significant difference between the standard older ($M = -.50$, $SD = 1.07$) and highly educated older ($M = .66$, $SD = .97$) adults, $t(75) = 4.91$, $p < .001$.

2.2.3. *Correlations between neuropsychological test performance and item and associative memory performance*

We assessed the relationships between neuropsychological functioning and item and associative memory performance by computing partial correlations (controlling for age, gender, and years of formal education) between levels of memory performance (i.e., corrected recognition) for all of the older adults during tests of both item and associative memory[5] and level of neuropsychological functioning as indicated by the MTL-General, MTL-Verbal, MTL-Average (averaging across the two MTL factors), and Frontal factor scores. As Table 4 indicates, overall associative memory was positively (and in several cases) significantly related to frontal and especially to MTL functioning whereas item memory was not. Furthermore, higher levels of MTL, but not Frontal, functioning were significantly correlated with smaller differences between item and associative memory performance (i.e., smaller associative deficit) for older adults.

2.3. Discussion

In the current experiment we examined whether a high level of education preserves associative memory processes, which normally decline in standard older adults. The findings from this experiment suggest that, at least in the case of associative memory for person–action pairings, a high level of education plays a relatively sparse role in protecting these processes from the effects of cognitive aging. Indeed, the memory performance data revealed an overall age-related associative

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[5] We also computed “item minus associative” memory difference scores to examine the relationship between levels of neuropsychological functioning and the magnitude of the associative deficit for each individual older adult. Note that we expect negative correlations for these comparisons, which indicate that increases in the level of neuropsychological functioning should be associated with decreases in the magnitude of the associative deficit. See Table 4 for statistical values related to these partial correlations.

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Table 4 – Experiment 1 and Experiment 2 (as well as the combined data for both experiments) partial correlations of both overall item and associative memory performance (corrected recognition) and the magnitude of the associative deficit (i.e., Item$_{\text{(H-FA)}}$ minus Associative$_{\text{(H-FA)}}$ memory performance) with factor scores indicative of level of neuropsychological functioning in all older adults.

	MTL-General	MTL-Verbal	MTL-Average	Frontal
Experiment 1				
Item$_{\text{(H-FA)}}$	$r(72) = -.09, p = .43$	$r(72) = -.10, p = .39$	$r(72) = -.12, p = .31$	$r(72) = .01, p = .98$
Associative$_{\text{(H-FA)}}$	$r(72) = .20, p = .08$	$r(72) = .20, p = .10$	$r(72) = .24, p = .04^{*}$	$r(72) = .26, p = .03^{*}$
Difference score: Item$_{\text{(H-FA)}}$−Assoc$_{\text{(H-FA)}}$	$r(72) = -.22, p = .07$	$r(72) = -.21, p = .07$	$r(72) = -.26, p = .02^{*}$	$r(72) = -.20, p = .08$
Experiment 2				
Item$_{\text{(H-FA)}}$	$r(90) = -.04, p = .72$	$r(90) = .22, p = .04^{*}$	$r(90) = .12, p = .27$	$r(90) = -.04, p = .70$
Associative$_{\text{(H-FA)}}$	$r(90) = .25, p = .02^{*}$	$r(90) = .31, p = .003^{**}$	$r(90) = .35, p = .001^{**}$	$r(90) = .14, p = .19$
Difference score: Item$_{\text{(H-FA)}}$−Assoc$_{\text{(H-FA)}}$	$r(90) = -.30, p = .004^{**}$	$r(90) = -.15, p = .17$	$r(90) = -.28, p = .008^{**}$	$r(90) = -.18, p = .08$
Experiment 1 & 2				
Item$_{\text{(H-FA)}}$	$r(167) = -.06, p = .48$	$r(167) = .09, p = .22$	$r(167) = .03, p = .73$	$r(167) = -.04, p = .66$
Associative$_{\text{(H-FA)}}$	$r(167) = .22, p = .004^{**}$	$R(167) = .24, p = .002^{**}$	$r(167) = .29, p = .001^{**}$	$r(167) = .17, p = .03^{*}$
Difference score: Item$_{\text{(H-FA)}}$−Assoc$_{\text{(H-FA)}}$	$r(167) = -.26, p = .001^{**}$	$r(167) = -.17, p = .03^{*}$	$r(167) = -.26, p = .001^{**}$	$r(167) = -.19, p = .02^{*}$

$^{*}p < .05$; $^{**}p < .01$.

deficit, wherein older adults, regardless of level of education, exhibited large declines in associative memory performance, relative to younger adults, despite much smaller decline in item memory performance.

Moreover, the current neuropsychological test battery findings revealed non-significant differences between the two older adult groups with respect to MTL functioning. However, in line with one of our predictions, significant differences in frontal lobe functioning were observed between standard older and highly educated older adults, with relatively higher functioning exhibited by the highly educated older adults. Curiously, despite evidence of higher frontal lobe functioning in the highly educated compared to standard older adults, we observed an age-related associative memory deficit in both of these older adult groups relative to younger adults. Notably, however, we observed significant positive correlations between associative, but not item, memory and neuropsychological functioning in general (e.g., frontal lobe, MTL) when considering all of the older adults collectively. Furthermore, these correlations indicated that the age-related associative deficit (item minus associative memory performance) was significantly related to MTL functioning and less to Frontal functioning.

Overall, this pattern of results indicates that, at least for the highly contextual and visually presented person–action pairings examined in the current experiment, the age-related associative memory deficit persists despite higher education and higher frontal lobe functioning. Nevertheless, it may be the case that the benefits of a high level of education and frontal functioning in preserving associative memory materialize during the formation, storage, and retrieval of other, non-visual associations between other types of item components (e.g., verbal material). The purpose of Experiment 2 was to examine this possibility.

3. Experiment 2

In Experiment 2, we again examined item and associative memory performance in standard younger and older adults as well as highly educated older adults. In contrast to Experiment 1, which examined item and associative memory for episodes that were visual, in Experiment 2 we examined memory for aurally presented verbal material (unrelated word pairs).

3.1. *Methods*

3.1.1. *Participants*

Participants (see Table 1) were 43 older adults (18 females; age range = 65–87, *M* = 73.05, *SD* = 6.70), most of whom had attained a doctoral degree, (years of formal education: *M* = 20.98; *SD* = 1.71, range = 19–28 years of education), 52 older adults without advanced degrees (35 females; age range = 65–84, *M* = 72.50, *SD* = 5.28; education: *M* = 14.68, *SD* = 1.88, range = 12–18 years of education, which is similar to other studies examining item and associative memory)[6] and 60 younger adults (30 females; age range = 18–22, *M* = 18.80, *SD* = 1.01; education: *M* = 12.36, *SD* = .76, range = 12–16 years of education). All participants (except 3 highly educated older adults) did not take part in Experiment 1. Both the advanced degree holding older adults and standard older adults resided in the community, were prescreened according to the same inclusion criteria established for Experiment 1, reported no serious physical or mental health issues, and were compensated $15 for their participation. Younger adults were undergraduate students from introduction to psychology courses at the University of Missouri, who participated in exchange for course-related credit. All participants provided informed consent and all protocols were approved by the institutional review board at the University of Missouri. There was a significant difference

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[6] MMSE scores were obtained for only a subset of the older adult participants from each group [standard older adults: $N = 15$, $M = 28.0$; highly educated older adults: $N = 5$, $M = 29.4$; $t(18) = 2.00$, $p = .06$]. Notably, the average MMSE scores obtained from these older adults were well above the standard cut-off score (i.e., 24) suggesting that the current older adult groups exhibited normal cognition.

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in level of education between the three groups of participants, $F(2, 153) = 428.57$, $p < .001$. Bonferroni-corrected post-hoc comparisons revealed significant differences in the number of years of education between each of the three groups of participants (all p's < .001), with the highly educated group of older adults showing the highest level of education and the younger adults showing the lowest level.

3.1.2. *Stimulus materials*

Stimuli were unrelated word pairs presented aurally via headphones. Study phases consisted of the presentation of 24 unrelated word pairs per block (stimulus presentation order was randomized). Test stimuli were single words (8 "old" targets, 8 "new" distractors per block) for each of the separate item test blocks, or word pairs (8 "intact" target pairs, 8 "recombined" distractor pairs) for the associative test blocks. Over three separate blocks this resulted in a total of 72 study pairs, 24 item test targets, 24 item test distractors (new items), 24 associative test targets, and 24 associative test distractors. Half of the items that were presented at study were presented again during the item test while the other half of the items presented during at test had not been presented during the study phase. Half of the word pairs in the associative test were presented intact while the other half of the associative test pairs were recombined, meaning the item components were not presented together originally during the study phase. The order of stimulus presentation in each test was randomized, as was test order (item test, associative test).

3.1.3. *Procedure*

Participants were instructed that they would hear word pairs (e.g., "lumber pigment") and that they should attend to each word individually and note that the two words were paired together, as they would be tested on individual words and word pairings during later tests. In a given block, 24 word pairs were presented aurally via headphones (2.5 sec per word pair, 2.5-second ISI). Following the study phase, participants completed an interpolated activity for 30 sec during which they were required to count backward by threes. Prior to each item test block, participants were informed that half of the items presented during the item test block would have been presented during the study phase while other half will not have been presented. During the item test block 16 single words were presented via headphones (8 targets, 8 distractors). Prior to each associative test block (8 targets, 8 distractors), which were also presented via headphones, participants were informed that half of the word pairs will have been presented during the preceding study phase while the other half will have been recombined from study to test, meaning that while both of the item components were presented originally, these components will not necessarily have been presented together during the study phase. Participants had 5 sec to respond after the onset of each test stimulus (single item or associative test pair) and were instructed to respond using keys on the keyboard labeled "old" or "new". Note that a given word appeared either in the item or in the associative test.

Prior to beginning the 3 study-tests blocks of the actual experiment, participants completed a brief practice block which included 6 study pairs followed by the interpolated activity, and finally a practice item test block with 4 test items (2 targets, 2 distractors) and a practice associative test block with 4 associative test pairs (2 targets, 2 distractors). Test order (item, associative) was counterbalanced across participants in each group. After completing the item and associative memory task, as was the case in Experiment 1, all older adults were administered nine neuropsychological tests including the frontal lobe function (five) and medial temporal lobe function (four) subtests (e.g., Glisky et al., 1995, 2001). Together, the single experimental session involving the Experiment 2 task and neuropsychological test battery took approximately 90 min to complete.

3.2. Results

3.2.1. *Item and associative memory performance*

As in Experiment 1, we submitted the corrected recognition values (see Table 5 and Fig. 2) to a 3 × 2 repeated-measures ANOVA including the factors of age (younger, standard older, highly educated older) and memory test (item, associative). No main effect of age was evident, $F(2, 152) = 1.63$, $p = .20$, indicating similar performance for younger ($M = .48$, $SD = .21$), standard older ($M = .42$, $SD = .22$), and highly educated older adults ($M = .48$, $SD = .21$). A main effect of test was observed, $F(1, 152) = 23.90$, $p < .001$, $\eta_p^2 = .14$, with greater accuracy during tests of item ($M = .50$, $SD = .13$) compared to associative ($M = .42$, $SD = .17$) memory. The interaction between the factors of age and test was marginally significant, $F(2, 152) = 2.41$, $p = .09$.

Although the overall age by test interaction was only marginally significant, the trend toward the pattern of the interaction observed in the current experiment was similar to that observed in Experiment 1. Thus, to assess whether there was an overall age-related associative memory deficit, we combined the two older adults groups into a single older adult group prior to conducting follow-up analyses on the marginally significant interaction. As such, we conducted a follow-up 2 age (younger adults, all older adults) × 2 test (item, associative) ANOVA, which indicated a significant age by test

Table 5 – Experiment 2: Mean corrected recognition (i.e., proportion hits minus proportion false alarms) values (with standard deviations) for each experimental condition for younger and older adults.

	Younger adults	Standard older adults	Highly educated older adults
Proportion hits			
Item	.70 (.16)	.66 (.15)	.69 (.14)
Associative	.70 (.16)	.65 (.18)	.73 (.14)
Proportion false alarms			
Item	.20 (.13)	.18 (.15)	.16 (.16)
Associative	.24 (.14)	.31 (.19)	.29 (.19)
Corrected recognition			
Item	.50 (.22)	.48 (.20)	.53 (.20)
Associative	.46 (.26)	.34 (.28)	.44 (.27)

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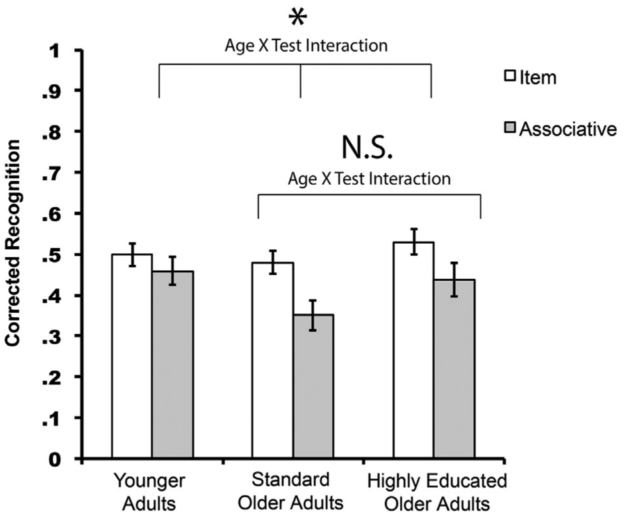

Fig. 2 – Experiment 2 – Results depicting the corrected recognition (i.e., proportion hits minus proportion false alarms) for each subgroup for each memory test condition: The abscissa depicts the younger, standard older, and highly educated older adult subgroups while their levels of performance in both item and associative recognition memory (corrected recognition) is plotted along the ordinate. Error bars represent the standard error of the mean in each test condition. Asterisks denote a significant age by test interaction between the younger adults and all older adults ($p < .05$). N.S. denotes a non-significant age by test interaction between the older adult groups.

interaction, $F(1, 153) = 4.17$, $p = .04$, $\eta_p{}^2 = .03$. Follow-up paired samples t-tests[7] indicated no difference between item ($M = .50$, $SD = .22$) and associative ($M = .46$, $SD = .26$) memory test performance for the younger adults, $t(59) = 1.58$, $p = .12$. However, for the older adults, associative memory performance ($M = .39$, $SD = .28$) was significantly lower than item memory ($M = .50$, $SD = .20$) performance, $t(94) = 4.67$, $p < .001$. Importantly, a follow-up 2 × 2 ANOVA comparing performance in the two groups of older adults revealed no significant interaction between group and test $F(1, 93) = .58$, $p = .45$, further confirming that the age-related associative memory deficit did not vary with level of education (see Fig. 2).

3.2.2. *Neuropsychological test performance*

The strategy and factor analytic technique used and described in Experiment 1 (see Section 2.2.2 above) was again applied to the eight neuropsychological test scores obtained from the standard older and highly educated older adults examined in Experiment 2. Again, studentized residual scores resulting from these regression analyses were used to conduct an exploratory factor analysis using maximum likelihood estimation as the extraction method. Kaiser-Meyer-Olkin's measure of sampling adequacy was low, but sufficient (.62) and Bartlett's test of sphericity was significant, $\chi^2_{\text{approx}}(28) = 354.38$, $p < .001$. Factors with eigenvalues greater than 1 were extracted and subjected to oblique rotation, revealing that the variance within the eight neuropsychological test scores included in the factor analysis loaded onto three distinct factors, as was the case in Experiment 1 (see Table 6 for means, standard deviations, factor loadings, eigenvalues, and percentage of variance explained). Of these factors, one factor loaded onto the Family Pictures I and Family Pictures II (MTL-General factor). A second factor loaded onto the Logical Memory I and Logical Memory II tests (MTL-Verbal factor). The third and final factor loaded onto the FAS, Mental Arithmetic, Mental Control, and Backward Digit Span tests (Frontal factor).

Using this three-factor solution, factor scores for each participant were computed (using Bartlett's method). Standardized scores for each participant (i.e., studentized residuals) corresponding to each of the eight neuropsychological tests were multiplied by the corresponding standardized scoring coefficient for each test obtained from the resulting factor score coefficient matrix for each factor and summed to create a weighted factor score representing a given participant's relative performance on each factor (negative values = below the mean; positive values = above the mean). To examine differences in neuropsychological functioning between the standard older and highly educated older adults, we submitted the weighted factor scores for the participants from each of these groups corresponding to each of the three separate factors to independent samples t-tests. No significant difference between the standard older ($M = -.02$, $SD = .98$) and highly educated older adults ($M = .03$, $SD = 1.09$) was observed between the weighted factor scores corresponding to the MTL-General factor, $t(93) = .22$, $p = .82$. Similarly, there was no difference between the factor scores for the standard older ($M = .09$, $SD = .86$) and highly educated older adults ($M = -.11$, $SD = 1.15$) corresponding to the MTL-Verbal factor, $t(93) = .99$, $p = .33$. However, the between-groups comparison of the weighted factor scores corresponding to the Frontal factor indicated a significant difference between the standard older ($M = -.33$, $SD = 1.10$) and highly educated older ($M = .40$, $SD = 1.10$) adults, $t(93) = 3.22$, $p = .002$.

3.2.3. *Correlations between neuropsychological test performance and item and associative memory performance*

As in Experiment 1, we assessed the relationships between neuropsychological functioning and item and associative memory performance by computing partial correlations (controlling for age, gender, and years of formal education) between levels of memory performance (i.e., corrected recognition) for all of the older adults during tests of both item and associative memory and level of neuropsychological functioning as indicated by the MTL-General, MTL-Verbal, MTL-Average (averaging across the two MTL factors), and Frontal factor scores. As Table 4 indicates, aside from the MTL-Verbal factor, item memory performance was not correlated with neuropsychological test performance. In contrast, whereas MTL functioning (especially the MTL-Average score) was correlated consistently and significantly

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[7] An independent samples t-test indicated that the difference between younger and older adults was non-significant in the comparison of item (younger: $M = .50$, $SD = .22$; older: $M = .50$, $SD = .20$) memory, $t(153) = .14$, $p = .89$. This difference was relatively larger, but non-significant, in the between-age groups comparison of associative (younger: $M = .46$, $SD = .26$; older: $M = .39$, $SD = .28$) memory, $t(153) = 1.56$, $p = .12$.

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Table 6 – Experiment 2: Neuropsychological test raw score means and loadings extracted from oblique rotation of the maximum likelihood estimation factor analysis.

Test	Raw scores Mean (SD)	Factor 1 MTL-General	Factor 2 MTL-Verbal	Factor 3 Frontal Lobe
Logical Memory I	44.09 (9.55)	–	.98	–
Family Pictures I	37.72 (11.33)	.95	–	–
Logical Memory II	26.18 (8.18)	–	.82	–
Family Pictures II	37.45 (11.31)	.94	–	–
Wisconsin Card Sorting Task	5.43 (1.23)	–	–	–
Controlled Oral Word Association	38.68 (10.45)	–	–	.33
Mental Arithmetic	12.14 (3.26)	–	–	.52
Mental Control	27.25 (5.98)	–	–	.47
Digit Span (backwards)	7.19 (2.16)	–	–	.82
Eigenvalue		1.68	2.14	1.10
Variance (%)		21.02	26.80	13.72

with associative memory, Frontal functioning was not. Furthermore, higher levels of MTL, but not Frontal, functioning were significantly correlated with smaller differences between item and associative memory performance (i.e., smaller associative deficit) for older adults.

3.3. *Discussion*

In the current experiment, using aurally presented word pairs, we examined whether a high level of education preserves associative memory processes, which tend to decline in standard older adults. Converging with the findings from Experiment 1, the results of the current experiment indicate that for aurally presented verbal material (i.e., word pairs), a high level of education does not protect older adults from the age-related associative memory deficit. Results from the current experiment indicated that a typical overall age-related associative deficit was observed for all older compared to younger adults, with no significant differences in the magnitude of the associative deficit between the two older adult groups.

As was the case in Experiment 1, the neuropsychological test data from the current experiment revealed no differences in MTL functioning between the two groups of older adults. However, again there were significant differences in frontal lobe profiles with evidence of higher frontal lobe functioning in the highly educated compared to the standard older adults. While higher frontal lobe functioning should underlie access to strategic processes, which would conceivably benefit associative memory performance, the age-related associative deficit was present even in the highly educated older adults with high frontal lobe functioning. As such, simply having a higher level of education appears to be insufficient to reduce age-related declines in associative memory performance. Interestingly, when considering both groups of older adults collectively, associative, but not item, memory performance was correlated with overall MTL, but not frontal, functioning.

3.4. *Cross-experimental analyses of Experiment 1 and Experiment 2*

In an attempt to assess the overall effects of age group and test across both experiments and also strengthen statistical power, we combined the corrected recognition values from Experiment 1 (i.e., the Day 1 and Day 2 averaged values) and Experiment 2 pertaining to performance in the item and associative test conditions for all three groups of participants (younger, standard older, highly educated older adults). The resulting 3 (group) × 2 (test) ANOVA revealed the same overall pattern observed in the separate analyses pertaining to each of the individual experiments. Namely, there was a main effect of age, $F(2, 271) = 6.88$, $p = .001$, $\eta_p^2 = .05$. Overall, younger adults ($M = .50$, $SD = .18$) significantly outperformed the standard older adults ($M = .41$, $SD = .19$, $p < .001$) but did not outperform the highly educated older adults ($M = .44$, $SD = .18$, $p = .11$). There was no significant difference in overall performance between the two older adult groups ($p = .56$). The main effect of test was significant, $F(1, 271) = 42.14$, $p < .001$, $\eta_p^2 = .14$, with higher levels of performance during the item tests ($M = .49$, $SD = .10$) compared to associative tests ($M = .41$, $SD = .14$). Crucially, the age by test interaction was significant, $F(2, 271) = 5.51$, $p = .005$, $\eta_p^2 = .04$, suggesting the presence of an age-related associative memory deficit across both experiments.

To assess whether there was an overall age-related associative memory deficit, we combined the two older adults groups into a single older adult group prior to conducting follow-up analyses on the significant interaction. A follow-up 2 (younger adults, all older adults) × 2 (item, associative) ANOVA indicated a significant age by test interaction, $F(1, 272) = 9.25$, $p = .003$, $\eta_p^2 = .03$. Follow-up paired samples t-tests[8] indicated a marginally significant difference between item ($M = .52$, $SD = .19$) and associative ($M = .49$, $SD = .23$) memory test performance for the younger adults, $t(101) = 1.79$, $p = .08$. However, for the older adults, associative memory performance ($M = .37$, $SD = .24$) was significantly lower than item memory ($M = .48$, $SD = .18$) performance, $t(171) = 6.41$, $p < .001$. Importantly, a follow-up 2 × 2 ANOVA comparing

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[8] An independent samples t-test indicated that the difference between younger and older adults was only marginally significant in the comparison of item (younger: $M = .52$, $SD = .19$; older: $M = .48$, $SD = .18$) memory, $t(272) = 1.78$, $p = .08$. This difference was significant in the between-age groups comparison of associative (younger: $M = .49$, $SD = .23$; older: $M = .37$, $SD = .24$) memory, $t(272) = 4.01$, $p < .001$.

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performance in the two groups of older adults revealed a non-significant interaction between group and test $F(1, 170) = 1.49$, $p = .22$, suggesting that the age-related associative memory deficit did not vary with level of education.

Finally, in an attempt to examine the different patterns of correlations observed in Experiment 1 and Experiment 2, we collapsed across the data for all older adults ran in both experiments and computed partial correlations (again controlling for age, gender, and education) to examine the relationship between memory test and neuropsychological test performance. As presented in Table 4, the cross-experimental correlations were significant when comparing associative, but not item, memory and all of the neuropsychological test factors. Moreover, the magnitude of the associative deficit (e.g., item minus associative difference scores) was significantly correlated with both MTL and frontal functioning.

4. General discussion

Experiments 1 and 2 examined the role of a high level of education in remediating the age-related associative memory deficit frequently observed in the cognitive aging literature. Both experiments revealed a pervasive age-related deficit primarily impacting associative memory for both standard older and highly educated older adults compared to standard younger adults. These findings suggest that education does not provide an effective dose of CR, at least with respect to the preservation of associative memory processes in older adults. Neuropsychological assessment of the two older adult groups indicated similar MTL functioning but differential frontal lobe functioning across both experiments. Namely, higher frontal lobe functioning was observed in the highly educated compared to standard older adults. Taken together, the findings from both experiments individually, further supported by analyses conducted by combining the data from both experiments, indicate that a high level of education, although associated with high frontal lobe functioning, did not improve associative memory performance.

The current experiments provide an interesting pattern of results regarding the influence of level of education and neuropsychological (e.g., frontal lobe, MTL) functioning on age-related differences in associative memory. Interestingly, previous research has implicated both frontal and MTL regions as plausible neural mechanisms underlying the item and associative memory processes examined in the current study. Generally, neuroimaging research indicates that MTL and PFC structures are integral to episodic memory processes (Cabeza, 2006; Mayes, Montaldi, & Migo, 2007; Mitchell & Johnson, 2009). Functional magnetic resonance imaging (fMRI) research indicates that MTL structures are activated during the encoding of item and item–feature associations (e.g., hippocampal cortex; perirhinal cortex) during memory tasks (Staresina & Davachi, 2008; Westerberg, Voss, Reber, & Paller, 2012). Additionally, regions within PFC show greater activation during associative compared to item memory tests (Blumenfeld, Parks, Yonelinas, & Ranganath, 2011; Lepage, Brodeur, & Bourgouin, 2003). With respect to aging, although structural and functional declines in PFC regions are more robust, declines within MTL regions are evident as well (see Cabeza, 2001; Raz, 2000, 2004). Structural MRI studies indicate that, even for older adults, greater hippocampal volume and subfield volumes are correlated with higher levels of associative memory performance (hippocampal: Rodrigue & Raz, 2004; CA3-4 and dentate gyrus: Shing et al., 2011).

Notably, other findings indicate positive correlations between hippocampal volume and associative memory performance for younger, but not older, adults, suggesting that other brain regions may be required to supplement older adults' associative memory processes (Rajah, Kromas, Han, & Pruessner, 2010). Indeed, fMRI evidence has revealed that older adults recruit PFC regions when retrieving contextual associations, potentially indicative of compensatory processing (Rajah, Languay, & Valiquette, 2010). Finally, larger gray-matter volume within PFC regions is correlated positively with levels of associative memory performance in older adults (Becker et al., 2015). Together, these recent findings implicate structural and functional MTL-hippocampal and PFC integrity as important neural mechanisms mediating inter-individual variability within older adults' associative memory performance.

In both experiments within the current study, frontal lobe functioning for the highly educated older adults was superior to that of the standard older adults. Somewhat surprisingly, diverging from what we might reasonably predict given the patterns of results observed in the aforementioned neuroimaging literature, although highly educated older adults exhibited higher levels of frontal lobe functioning relative to standard older adults, both groups exhibited an age-related associative memory deficit. In contrast, no overall differences in level of MTL functioning were observed between these two groups of older adults. Finally, in an attempt to further examine the current findings, and how they relate to the neuroimaging literature, we assessed the relationships between neuropsychological functioning and item and associative memory performance for all older adults in Experiment 1, Experiment 2, and, in an attempt to improve the statistical power pertaining to these correlational analyses, collapsed performance across all of the older adults from Experiments 1 and 2.

Several differences emerged between Experiment 1 and Experiment 2 regarding the correlations between memory performance and each type of MTL and frontal functioning (see Table 4). For instance, MTL-Verbal correlated with item memory performance in Experiment 2 but not Experiment 1, likely due to the use of distinct stimulus materials and presentation format (Experiment 1: visual; Experiment 2: verbal material, presented aurally). Moreover, the variations between Experiment 1 and Experiment 2 with respect to the marginal and statistically significant correlations between associative memory performance and MTL or frontal functioning are likely related to statistical power (e.g., smaller sample of older adults overall in Experiment 1). Finally, it may be the case that the significant relationship between associative memory and frontal functioning in Experiment 1, but not Experiment 2, emerged as function of the longer delay period used in Experiment 1 (e.g., hours) compared to Experiment 2 (e.g., minutes). Importantly, the relatively well-powered correlational analyses collapsed across

Experiments 1 and 2 revealed a consistent pattern wherein associative, but not item, memory performance was significantly correlated with both MTL and frontal functioning. Overall, the magnitude of the associative deficit, across both Experiments 1 and 2, was significantly correlated with MTL *and* frontal functioning, partially resolving the discrepancies between the separate correlational analyses pertaining to each individual experiment (see Table 4).

One factor that may differentiate the current results from both the previous behavioral and neuroimaging findings is that the average ages of the older adult samples examined in previous studies (e.g., 66.55 y.o.: Angel et al., 2010; 60 y.o.: Becker et al., 2015; 67.73: Rajah, Kromas, et al., 2010, Rajah, Languay, et al., 2010; 65.60 y.o.: Shimamura et al., 1995) were relatively younger than that of the older adults examined in the current work (e.g., $M = 72.75$ years old overall). Another factor contrasting with previous behavioral findings of preserved associative memory processes in highly educated older adults (e.g., Angel et al., 2010; Shimamura et al., 1995) relates to the manner by which associative memory is tested. These studies used paired-associate recall or cued-recall tasks, which, as was mentioned in the Introduction, are somewhat ambiguous with respect to the separate contribution of item and associative memory. In the current study, distinct item and associative test conditions were used in order to independently examine the influence of age and level of education in each type of memory.

Notably, despite the lack of significant differences in the magnitude of the age-related associative deficit between the current standard and highly educated older adults, higher levels of frontal functioning were evident for the highly educated. Interestingly, recent neuroimaging work suggests that episodic memory task related activity within PFC regions is *positively* correlated with structural gray matter volume within MTL structures (Maillet & Rajah, 2011; Rosen et al., 2005). This evidence suggests that gray matter volumes within MTL structures are correlated with functional activation in PFC regions (for a review see Maillet & Rajah, 2013). These observations of positive correlations between MTL volume and PFC activity seem to diverge from the predictions proposed by compensatory models, which predict increased PFC activity with decreases in MTL structural volume (e.g., Park & Gutchess, 2005; Park & Reuter-Lorenz, 2009). In other words, it may be the case that structural integrity within both MTL *and* frontal regions concurrent with high levels of functioning in these regions is necessary to maintain associative memory processes across the lifespan. This notion appears consistent with the current findings of an overall age-related associative deficit despite the fact that the highly educated older adults in the current experiments exhibited higher frontal functioning than standard older adults. Furthermore, this notion is supported by the relationship between behavioral and neuropsychological performance when older adults from both of the current experiments are combined, as associative memory performance was positively correlated with *both* MTL and frontal functioning, suggesting that associative memory may be relatively spared for older adults with higher levels of MTL *and* frontal functioning.

Related to the differences in frontal functioning observed between the two groups of older adults, previous findings indicate that standard older, relative to younger, adults have difficulties in initiating strategies (Hertzog, Fulton, Mandviwala, & Dunlosky, 2013; Naveh-Benjamin et al., 2009). However, explicit instructions regarding efficient strategy use can be used to improve associative memory performance in older adults (Naveh-Benjamin et al., 2007). Moreover, gray-matter volume in PFC regions is positively correlated with semantic memory-based strategy use in older adults (Kirchhoff, Gordon, & Head, 2014). With respect to the overall findings observed in Experiments 1 and 2, it may be the case that, although the highly educated older adults had higher frontal lobe functioning compared to standard older adults, potentially useful strategic processes were not available or simply not allocated to support associative memory processing demands, resulting in a pervasive age-related associative deficit. Quite possibly, the highly educated might require explicit instructions regarding the benefits of strategy use to improve associative memory performance over and above the benefits previously observed for standard older adults.

It is important to note the limitations of the current work. First, although we compared item and associative memory performance in standard and highly educated older adults to that of standard younger adults, no “highly educated” younger adult control group was tested (e.g., as used in Shimamura et al., 1995). However, given that even the highly educated older adults showed an age-related associative deficit in Experiments 1 and 2, comparisons with highly educated younger adult controls are likely to increase the magnitude of the observed deficit given that we might predict the best performance for the high ability younger adults compared to all other groups.

Second, as mentioned above, while the neuropsychological results obtained for both groups of older adults examined in the current experiments are informative, they lack the precision and resolution available to neuroimaging techniques. Future examinations employing structural and functional MRI to assess putative neural mechanisms underlying both associative memory binding processes (e.g., MTL, PFC) and strategic processes (e.g., PFC) in highly educated and standard older adults is an important next step. Despite these limitations, the current findings indicate that age-related declines in associative memory processes are pervasive, and emerge even for older adults with high frontal lobe functioning and a high level of education.

5. Conclusion

The current experiments identified distinct conditions under which a high level of education can fail to preserve associative memory processes in older adults. When binding of visual components was required, the age-related associative deficit was evident in both highly educated and standard older adults. The associative deficit was also observed for all older adults, regardless of level of education, during attempts to bind aurally presented verbal components (i.e., unrelated words) in associative memory. In both experiments, highly educated older adults exhibited higher frontal lobe functioning compared to age-matched older adult controls, but,

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interestingly, frontal lobe functioning did not mediate associative memory performance. These results suggest that providing explicit instructions to employ strategic processes during associative memory tasks (e.g., at encoding and retrieval) may be necessary to observe any benefits of a high level of education on associative memory performance. Future neuroimaging investigations of the role of education in preserving associative memory processes in older adults will further establish the role of the putative MTL and frontal lobe mechanisms examined in the current work.

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