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Do Young and Older Adults Rely on Different Processes in Source Memory Tasks? A Neuropsychological Study

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Source memory has consistently been associated with prefrontal function in both normal and clinical populations. Nevertheless, the exact contribution of this brain region to source memory remains uncertain, and evidence suggests that processes used by young and older adults may differ. The authors explored the extent to which scores on composite measures of neuropsychological tests of frontal and medial temporal function differentially predicted the performance of young and older adults on source memory tasks. Results indicated that a frontal composite measure, consistently associated with source memory performance in older adults, was unrelated to source memory in young adults, although it was sensitive to a demanding working memory task. The memory composite score, however, predicted performance in the young group. In addition, item and source memory were correlated in young but not older people. Findings are discussed in terms of age-related differences in working memory and executive functions, and differential binding processes necessary for item and source memory. The requirement to integrate item and source information at encoding appears to place greater demands on executive or working memory processes in older adults than in younger adults.

Keywords: source memory, neuropsychology, frontal function, young adults, older adults

Although source memory was initially defined narrowly as memory for the origin of information, more recently the construct has been used broadly to include any aspects of context associated with an event, including spatiotemporal, perceptual or affective attributes (Johnson, Hashtroudi, & Lindsay, 1993). Distinctions between content and context, however, are not straightforward, often depending on situational factors or an individual's goals. For these reasons, source has often been defined operationally in terms of experimenter instructions and the mapping between items and sources. In most experimental studies of source memory, there is a many-to-few mapping of items to sources: many sentences spoken in two voices, many concepts perceived or imagined, many objects in two locations or colors, or many words in one of two lists (e.g., Davidson & Glisky, 2002; Dodson & Shimamura, 2000; Glisky, Polster & Routhieaux, 1995; Henkel, Johnson, & DeLeonardis, 1998; Kuo & Van Petten, 2006). The many different stimuli (e.g., sentences) are defined as content, whereas the repeating aspects (e.g., two different voices) are defined as source or context. In addition, instructions or orienting tasks usually focus people's attention on the central content or item (cf. Chalfonte & Johnson, 1996). Notably, the type of materials need not define item and source; rather, the nature of the task and the instructions convey such information. Thus, for example, if people hear many voices speaking one of two sentences and are oriented to the voices, voices are treated as focal content, and the two sentences represent peripheral context (see Glisky, Rubin, & Davidson, 2001). Source memory is usually more difficult than item memory because it requires retrieval not just of the item, but of the conjunction of item and source. The encoding and retrieval of source information may thus require integrative processes to link item and source, which may not be necessary for item memory.

Source memory has been found to depend on processes associated with prefrontal function, and the initial evidence supporting this assertion came largely from studies of impaired populations and normally aging older individuals. For example, early studies of individuals with amnesia (Schacter, Harbluk, & McLachlan, 1984; Shimamura & Squire, 1987) found greater deficits in source memory than item memory only in those people who showed neuropsychological evidence of prefrontal damage. In a related vein, patients with frontal damage were found to be unimpaired on memory for facts but showed deficits when asked where or when the facts had been learned (Janowsky, Shimamura, & Squire, 1989; Johnson, O'Connor, & Cantor, 1997). Later studies with older adults showed greater age-related impairments in source than in item memory, deficits that in several cases were associated with poor performance on frontally dependent, executive function tests (e.g., Craik, Morris, Morris, & Loewen, 1990; Glisky et al., 1995; Parkin, Walter, & Hunkin, 1995). Although several studies (Gold et al., 2006; Henkel et al., 1998; Schwerdt & Dopkins, 2001; Thaiss & Petrides, 2003) have also implicated the medial temporal lobes (MTL) in source memory, the bulk of the literature has consistently identified frontal lobe (FL) function as a key contributor to source memory performance.

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An increasing number of studies have begun to examine the neural correlates of source memory in normal young adults, and these too have suggested prefrontal involvement. For example, in a functional magnetic resonance imaging (fMRI) study, Nolde, Johnson, and D'Esposito (1998) reported increased activation in the left prefrontal cortex (PFC) for source judgments (picture or word) relative to item recognition, and Slotnick, Moo, Segal, and Hart (2003) found greater left PFC activation during retrieval of the location of visual shapes compared to memory for the shapes themselves (see also Dobbins, Foley, Schacter, & Wagner, 2002; Kahn, Davachi, & Wagner, 2004; Rugg, Fletcher, Chua, & Dolan, 1999). Mitchell, Johnson, Raye, and Greene (2004) also identified regions of the left PFC that are activated to a greater degree during source memory than item memory in a working memory paradigm. Across these studies, the regions that have most often been associated with source memory tasks compared to item memory tasks are areas of the left ventrolateral PFC, including Brodmann's areas (BAs) 10, 44, 45, and 47, as well as left dorsolateral regions, namely BAs 9 and 46. Studies of source memory with event-related potentials have also reported PFC effects. For example, Senkfor and Van Petten (1998) found a late frontal positivity that was associated with attempts to retrieve source information but not item information (see also Johnson, Kounios, & Nolde, 1997; Trott, Friedman, Ritter, & Fabiani, 1997; Wilding & Rugg, 1996). The majority of the brain imaging studies, however, have examined brain activations only at retrieval, speculating that prefrontal brain regions are involved in systematic and controlled memory search and monitoring processes that are necessary for retrieval and/or evaluation of source-specifying information.

However, the precise contribution of PFC to source memory retrieval remains unclear. Furthermore, most studies have not been very informative with respect to frontally based encoding processes that might be particularly important for source memory and how such processes might be affected by age. Two fMRI studies of working memory provided suggestive information, however. Mitchell, Johnson, Raye, and D'Esposito (2000), in a task requiring short-term memory (8 s) for objects, locations, and objects in locations, found that young adults showed significantly greater activation in the left anterior hippocampus and the right PFC (BA 10) when memory for the object in location was tested compared to when memory for either object or location alone was tested. Older adults, on the other hand, did not show differential activation for the combination of attributes and were impaired only when required to remember the conjunction (see also Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000). These findings implicate the left hippocampus and the right medial PFC in the binding of item and source and suggest that older adults are deficient in these binding processes. Further evidence of the involvement of the right PFC in the integration of information in working memory was provided by Prabhakaran, Narayanan, Zhao, and Gabrieli (2000), who found increased activation in right BAs 9, 10, and 46 when integrated verbal and spatial information was held in working memory compared to maintenance of the two kinds of information separately.

Consistent with these fMRI studies, behavioral studies have suggested that integration of item and source during encoding may be impaired particularly in older adults with reduced FL function. In a series of experiments in our laboratory (Glisky et al., 2001), we demonstrated that older adults with below average scores on a composite measure of frontal function (low FL) were impaired on tests of source memory when attention was focused on the item at encoding. When given an orienting task that required them to integrate item and source at encoding, however, the deficits were completely eliminated. It is interesting that in these studies, the integrative orienting task did not benefit young adults or older adults with above-average frontal function (high FL), suggesting that these individuals may have integrated item and source spontaneously. These findings suggest that our composite measure of FL function might reflect the kinds of encoding processes that enable integration of multiple aspects of an experience. If such processes are initiated and implemented at encoding, a well-elaborated and readily retrievable memory trace may be laid down, reducing or eliminating the need for frontal control processes at retrieval.

Further evidence consistent with this view was recently reported by Kuo and Van Petten (2006), who found that when an integrative orienting task focused attention on the item–source conjunction (drawings in colors), the late prefrontal brain electrical activity typically associated with source retrieval attempts was eliminated, and performance improved. Kuo and Van Petten also reported that following the integrative orienting task, performance on item and source memory tasks was correlated, whereas after an item-alone orienting task, there was no correlation. Glisky et al. (2001) noted a similar correlation between the two tasks following integrative encoding in young adults. These findings suggest that young adults, particularly after integrative encoding, may perform item and source memory tasks similarly, perhaps accessing the same well-integrated memory trace, whereas older adults, despite achieving a level of performance similar to that of young adults, may use different processes for the two tasks.

Other evidence consistent with this notion was reported by Naveh-Benjamin and Craik (1996), who found that a deep level of processing produced similar benefits in item and source memory in young adults but not in older adults, for whom only an item memory benefit was observed. In an event-related potentials study, Swick, Senkfor, and Van Petten (2006) recently found that older adults displayed a prominent left frontal negativity in the 600-ms to 1,200-ms poststimulus interval during retrieval of source information that was not observed in young adults. They suggested that this reflected the use of alternate, perhaps compensatory, strategies in older adults that were not needed by young adults.

Taken together, these findings suggest that older adults may engage different processes or strategies for source memory tasks than for item memory tasks and that these strategies may require greater reliance on frontally based control processes. Younger adults, on the other hand, may engage similar processes for the two kinds of tasks. Alternatively, older adults may attempt to use the same strategies as young adults but may use them less efficiently. They may thus have to draw on additional frontal control processes at encoding, retrieval, or both to maintain performance on more demanding tasks, such as source memory.

It has been suggested that source memory tasks may require more recruitment of prefrontal brain regions simply because they are more difficult than item memory tasks. To test this hypothesis, Glisky et al. (2001) created a difficult item memory task requiring memory for novel voices and compared that to memory for the sentence that the voice spoke—arguably a relatively easy source memory task—in a many-voices-to-two-sentences paradigm. Although performance on the voice memory "item" task was relatively low, reflecting its difficulty, there was no hint that frontal function played a role. Performance on the source memory task, however, was again dependent on frontal function in the older adults, suggesting that frontal processes were not just recruited for all difficult tasks but played a more specific role in source memory.

As noted earlier, most of the behavioral evidence supporting the involvement of the FLs in source memory comes from studies of neurological patients and older adults—populations that exhibit impaired or low levels of performance on tests of executive function. To our knowledge, none of these studies has examined whether the source memory performance of unimpaired young adults is related to or supported by the same executive function processes as those used by older adults. Both behavioral and neuroimaging studies of source memory, however, have suggested that the processes engaged in source memory tasks by young and older adults may be different.

In the present study, we compared the performance of groups of younger and older adults, both of which were characterized according to their performance on tests of FL and MTL function, in a source memory paradigm in which the item and source memory tasks were equated for difficulty. We expected that the performance of older adults in the source memory task would depend on FL function, as previous research has shown, and that performance on item and source memory tasks would not be correlated in the older group. The extent to which neuropsychological function might affect the performance of young adults was an empirical question.

Before exploring the effects of neuropsychological function in younger adults, we first wanted to demonstrate (a) that the group of neuropsychological tests used in previous studies with older adults produced a similar factor structure in young adults and (b) that among normal young people, the variability in the two neurocognitive domains of interest—FL/executive function and MTL/memory function—was sufficient for their effects to be observed. In Experiment 1, we report the results of the neuropsychological findings in two groups of young people and compare them to the data from older adults, which have been updated from those previously reported in the literature. In Experiments 2 and 3, we then explored the relation of neuropsychological function in young people to their performance on two source memory tasks.

Experiment 1

Method

Participants. A group of 96 younger adults, ranging in age from 18 to 23 years ($M = 18.99$, $SD = 1.21$) and with a mean education level of 12.72 years ($SD = 0.99$), was drawn from a pool of undergraduates taking an introductory psychology course at the University of Arizona and received course credit for their participation.

A group of 227older adults between the ages of 65 and 90 years ($M = 73.39$, $SD = 5.39$), with a mean education level of 15.58 years ($SD = 2.44$), contributed test data for this study. These participants had previously completed neuropsychological testing as part of an ongoing aging study. All older adults were in good health, lived independently in the community, and reported no depression, dementia, or previous neurological problems that might have impaired their cognitive function. Their mean score on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) was 28.9. The older adult participants received monetary compensation for their participation.

A second, somewhat older group of 25 young adults (older young adults), ranging in age from 21 to 34 years ($M = 25.72$, $SD = 3.08$) and matched to the older adult group on education ($M = 16.28$, $SD = 1.94$), was recruited from the university community and was paid for their participation.

Materials and procedure. Participants were given a battery of 10 neuropsychological tests that have traditionally been associated with either FL/executive function or MTL/memory function. The neuropsychological tests had previously been submitted to an exploratory principal components analysis based on data from a group of 48 older adults, and this analysis had generated a two-factor solution, consistent with the FL–MTL distinction (see Glisky et al., 1995). This factor structure was later replicated with a separate group of 100 older adults (see Glisky et al., 2001). Because more recent versions of the neuropsychological tests had since been substituted for some of the original tests, we decided to conduct a confirmatory factor analysis with the updated tests and a new, larger group of 227 older adults. In addition, given that college students typically constitute the comparison group for older adults, we wanted to explore whether a similar factor structure existed in the group of 96 young participants. The 25 older young participants were included in this experiment both as an education-matched comparison group for the older adults and as a comparison to the young participants whose neural and cognitive functions may not have fully developed (Clark et al., 2006). The older young adults, however, were not included as an independent group in the factor analysis, because of the small sample size. The five tests included in the factor analysis that were expected to measure FL function were total number of words produced to the cues *F, A,* and *S* in a verbal fluency task (Spreen & Benton, 1977), the number of categories achieved on the modified Wisconsin Card Sorting Test (Hart, Kwentus, Wade, & Taylor, 1988), Backward Digit Span and Mental Control from the Wechsler Memory Scale–III (Wechsler, 1997), and Mental Arithmetic from the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981). The five tests hypothesized to measure MTL function were Logical Memory I, Verbal Paired Associates I, and Faces I (all from the Wechsler Memory Scale–III), Visual Paired Associates II from the Wechsler Memory Scale–Revised (Wechsler, 1987), and the Long-Delay Cued Recall measure from the California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 1987). The memory tests were selected to tap basic retention or consolidation processes traditionally thought to depend on the MTLs and to be minimally influenced by strategic factors that might be contributed by the FLs. The FL tests, on the other hand, were clearly not tests of long-term memory but were thought to tap executive control processes, perhaps those associated with working memory. In a paper presented recently at the Cognitive Aging Conference in Atlanta (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2006), our Frontal factor was found to share 98% of its variance with complex span tasks, consistent with the view that our FL factor represents executive functions associated with higher level working memory tasks. In hemodynamic studies, most of these tasks have been found to activate inferior and dorsolateral prefrontal regions, although superior frontal gyri have also been implicated.

A multiple-sample confirmatory factor analysis with EQS (Bentler, 1995) was conducted on the neuropsychological data from the young and older adult groups. We tested two models, one with and one without cross-sample constraints. The unconstrained model tested whether the two groups had the same factor structure; the constrained model tested whether the factor loadings were the same across the two groups. After the factor solutions were obtained, we computed factor scores for all groups. These scores were based on the sample of 323 and were obtained by averaging *z* scores for those tests loading on each factor (with unit weighting).

Results

The mean level of performance on each of the individual neuropsychological tests for each age group is shown in Table 1. Note that on two of the tests of FL function—tests of verbal fluency and mental arithmetic—older adults actually performed significantly better than the younger adults. On the majority of the tests, however, the older young group produced the highest scores, followed by the young group, and then the oldest group, although not all of these differences reached significance.

The results of the multiple sample confirmatory factor analysis indicated that the unconstrained model fit the data extremely well, confirming the two-factor structure in both old and young samples, $\chi^2(68) = 81.68$, $p = .12$, CFI = .971, RMSEA = .035. Factor loadings for the two age groups are shown in Table 2. All loadings were significant with the exception of mental arithmetic in young adults, and the two factors were correlated in both groups ($r = .55$ in old and .54 in young; $p\text{s} < .05$). The constrained model was a very poor fit by all criteria, $\chi^2(79, N = 323) = 322.71$, $p < .01$, CFI = .484, RMSEA = .139, indicating that the loadings in the two groups were different. An examination of the factor loadings in Table 2 suggested that the most notable difference between the two groups lay in the test of mental arithmetic, which did not load significantly on the FL factor in the young group but did in the older group. However, removing the cross-sample equality constraint for the mental arithmetic variable still did not provide an acceptable fit of the constrained model, $\chi^2(78, N = 323) = 299.74$, $p < .01$, CFI = .531, RMSEA= .133. Thus, the two-factor structure held up across age groups, but the strength of the loadings of the individual tests varied.

Table 2
Factor Loadings for 227 Older Adults and 96 Young Adults

	Young adults		Older adults	
Test	F1	F2	F1	F2
Wisconsin Card Sorting Test	.335		.425	
Backward Digit Span	.454		.564	
A verbal fluency (*FAS*) test	.650		.560	
Mental Arithmetic	.188		.594	
Mental Control	.644		.630	
Logical Memory I		.710		.536
Visual Paired Associates II		.442		.493
Verbal Paired Associates I		.637		.732
Faces I		.337		.291
CVLT Long-Delay Cued Recall		.691		.624

Note. F1 = Factor 1; F2 = Factor 2; CVLT = California Verbal Learning Test.

Because the Mental Arithmetic measure did not load significantly in the young group, that test was not included in the calculation of the factor scores for the young adults. Their FL factor scores were thus computed by averaging the *z* scores of the four other tests in Factor 1, which were equally weighted. In addition, the Mental Arithmetic test was omitted from calculations of factor scores in older and older young adults in this study in order to make direct comparisons of factor scores among age groups.

Figure 1 displays the box plots showing the median, overall range, and interquartile range of the FL scores for the three groups of participants. Visual inspection of this plot indicates that medians and interquartile ranges are roughly comparable across groups, but the total range of scores is largest in the older adult group and smallest in the older young group, with the young group falling in between. Means and standard deviations for the factor scores of the three groups are shown in Table 3. A one-way analysis of variance

Table 1
Neuropsychological Test Performance for the Three Age Groups in Experiment 1

	Young adults		Older young adults		Older adults	
Test (maximum score)	*M*	*SD*	*M*	*SD*	*M*	*SD*
Wisconsin Card Sorting Test (6)	5.09*	1.60	5.12	1.74	4.50*	1.75
Backward Digit Span (12)	7.14	2.03	7.84	1.99	7.58	2.24
A verbal fluency test	38.10*	10.60	41.92	8.14	41.86*	11.60
Mental Arithmetic (19)	10.78*	3.28	12.08	3.20	13.15*	3.26
Mental Control (40)	26.96	4.42	27.16	3.88	26.21	5.52
Logical Memory I (50)	25.57	6.38	26.80	4.05	25.16	6.60
Visual Paired Associates II (6)	5.64*†	0.85	6.00†	0.00	5.40*	1.08
Verbal Paired Associates I (32)	23.32†	5.64	25.00†	4.97	22.16	7.67
Faces I (48)	36.42	4.13	37.20	3.19	36.16	4.50
CVLT Long-Delay Cued Recall (16)	11.44†	2.62	12.52†	2.52	11.04	3.03

Note. CVLT = California Verbal Learning Test. The asterisk and the dagger indicate significant group differences, $p < .05$.

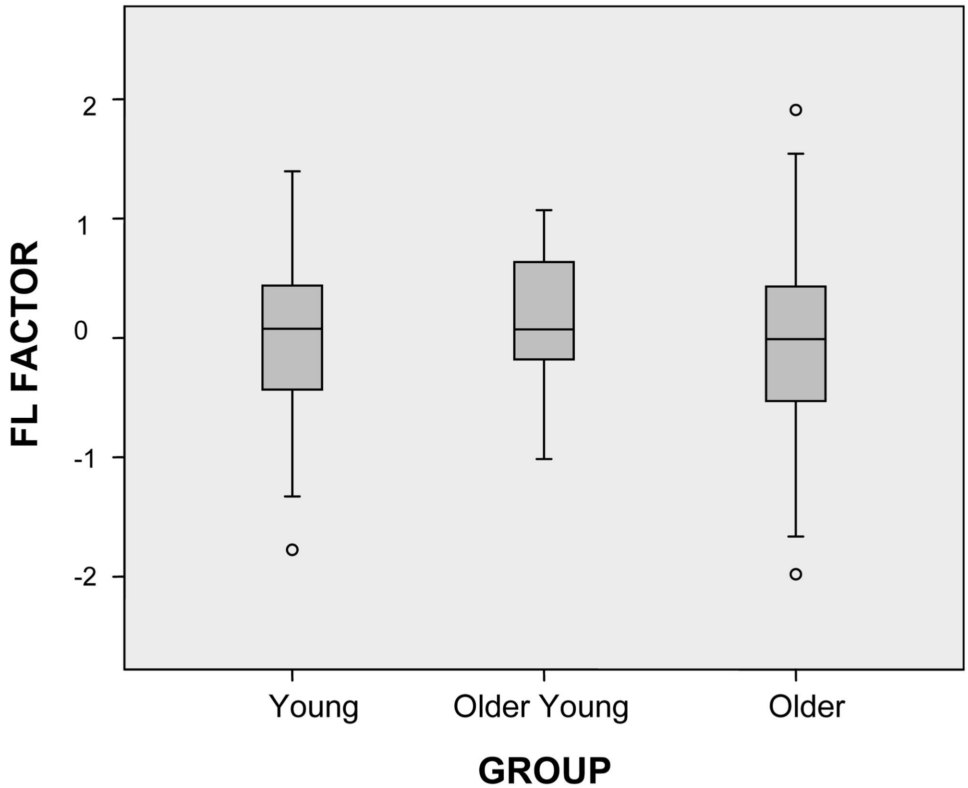

Figure 1. Comparison of frontal lobe (FL) factor scores for young, older young, and older adults, showing median, range, and interquartile range.

(ANOVA) comparing the means for the FL factor indicated no significant differences across groups ($F < 1$). Variances were also not significantly different, Levene's $F(2, 345) = 1.12$, $p = .33$.

Figure 2 displays the boxplots showing the median, overall range, and interquartile range of the MTL scores for the three groups of participants. Visual inspection of this plot shows a rather different pattern, with the older young group showing a higher median, a smaller overall range, and a smaller interquartile range than the older adult group and with the young group again falling in between. A one-way ANOVA indicated that the means were significantly different across groups, $F(2, 345) = 4.97$, $p = .007$, as were the variances, Levene's $F(2, 345) = 4.29$, $p = .01$ (see Table 3). Post hoc tests indicated that the older young group, which was matched to the older group on education, had a higher mean MTL factor score, $t(39) = 4.14$, $p < .01$, and less variance, $F(1, 250) = 6.16$, $p = .01$, than the older adult group. The young adults also had a lower mean MTL factor score than the older young group, $t(119) = 2.08$, $p = .04$, although variances did not differ significantly, $F(1, 119) = 1.88$, $p = .17$. Finally, the young and older adults were not significantly different in mean MTL scores, $t(201) = 1.72$, $p = .09$, although the scores of the older group were significantly more variable than those for the young group, $F(1, 321) = 3.627$, $p = .058$.

Table 3
FL and MTL Factor Scores in Young, Older Young, and Older Adults

	FL factor		MTL factor	
Group	*M*	*SD*	*M*	*SD*
Young	.02	.62	.09	.60
Older young	.15	.58	.36	.42
Older	.01	.70	−.04	.68

Note. FL = frontal lobe; MTL = medial temporal lobe.

Discussion

The results of this study confirm the two-factor structure in both young and older adults, although there were quantitative differences in the loadings on individual tests across age groups. All loadings in both age groups were significant except mental arithmetic in young people. Mental arithmetic is a task on which young adults perform significantly more poorly than older adults (see Table 1), perhaps reflecting greater reliance on calculators and less dependence on working memory. This may be the reason why this task did not share significant variance with the other executive function tasks.

Somewhat surprisingly, even with mental arithmetic removed from the factor, young adults did not outperform older adults on the composite measure of FL/executive function, nor were they less variable. Table 1 reveals that young adults were superior to older adults on the Wisconsin Card Sorting Test, whereas older

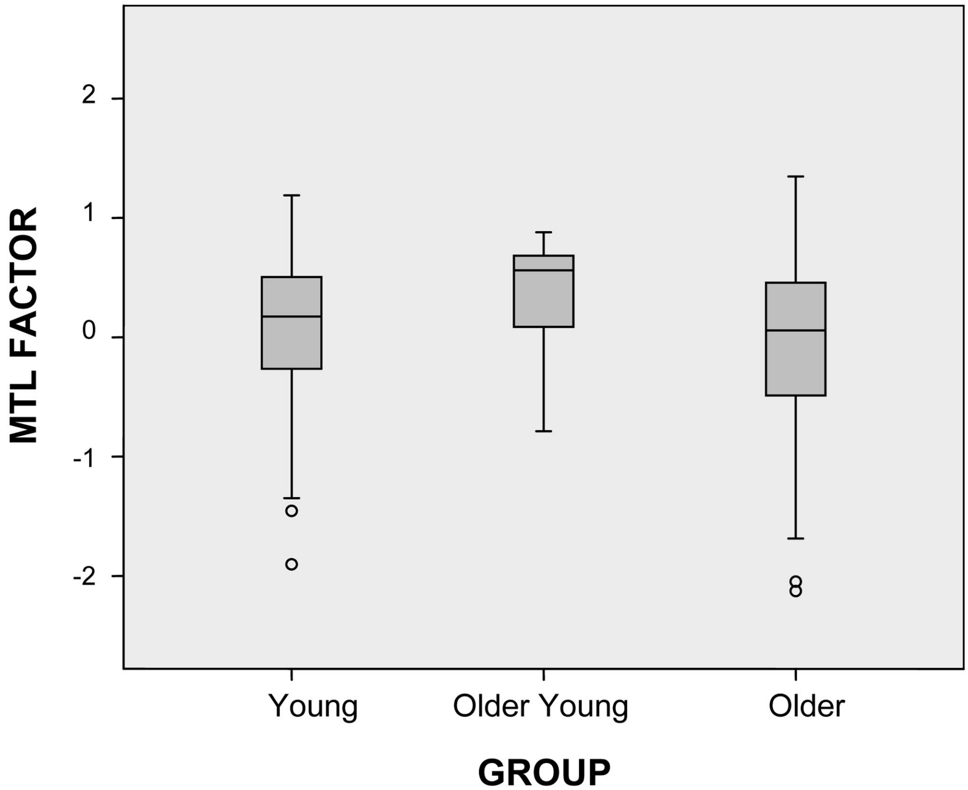

Figure 2. Comparison of medial temporal lobe (MTL) factor scores for young, older young, and older adults, showing median, range, and interquartile range.

adults were superior to younger adults on the verbal fluency task (the *FAS* task). The older young group appeared to be higher performing and less variable than the other two groups on all component tasks, but the smaller sample size may have precluded finding significant differences. Nevertheless, differences on the composite measure of FL function across the three groups were relatively small and nonsignificant, suggesting relative stability across the lifespan for the executive processes captured by our FL factor. We should point out that the use of a composite measure provides a more reliable and stable measure of FL function than any single measure (cf. Salthouse, Atkinson, & Berish, 2003). Many studies in the literature have reported age-related impairments on single measures of executive function, including the Wisconsin Card Sorting Test, the Stroop Test, the Tower of London, and the Self-Ordered Pointing Task (Bryan & Luszcz, 2000), but other studies have failed to find any age effects on other frontal tasks, including Letter Fluency, Backward Digit Span, and Mental Control (e.g., Lamar & Resnick, 2004), all three of which are part of our FL composite, although some studies have reported age differences. The literature is thus relatively inconsistent concerning which aspects of executive function are impaired in normal aging and which remain intact. Our FL factor likely represents only a subset of all possible executive functions, perhaps reflecting processes involved in working memory (see McCabe et al., 2006) or a more general nonmnemonic control process. We return to this issue in the General Discussion section.

On the MTL factor, however, there were significant group differences, but these differences primarily reflected a higher mean level of performance in the older young group relative to both the young and the older adults. In addition, both young groups were less variable than the older adults. This pattern may reflect continuing development of memory processes into the mid-20s or with continuing education, and a decline in the upper age ranges.

Experiment 2

The findings of Experiment 1 indicated that the two-factor structure previously found for older adults was maintained in young adults and that there was substantial variability in both factors among young individuals. The two factors thus might reasonably be used to explore the kinds of memory and executive processes used by young adults in tests of item and source memory. As noted earlier, a number of studies have suggested that the cognitive processes and brain regions engaged by younger adults in source memory tasks may be different than those recruited by older adults. In the present experiment, we attempted to replicate an earlier study conducted with young and older adults (Glisky et al., 2001, Experiment 1) in which there was a clear effect of FL function on source memory in the older group. (Neuropsychological function was not assessed in the young group.) In the 2001 study, we used the multiple voices/two sentences paradigm, in which participants were oriented to each of 12 voices speaking one of two sentences. Memory for each voice was subsequently tested in an item memory task, whereas memory for the conjunction of item and source (i.e., Which of the two sentences did each voice speak?) comprised the source memory task. Findings indicated that the FL factor was related to performance on the source memory task but not on the item task. Because the item memory task—memory for novel voices—was a quite difficult one, the findings suggested that the executive processes comprising the FL factor were not recruited just for any difficult or nonroutine memory tasks, as some theories suggest (e.g., Shallice, 1982), but instead appeared specific to source memory. We chose this same paradigm for the present study in order to equate the difficulty of the item and source memory tasks.

Method

Participants. A group of 66 young adults, ranging in age from 18 to 23 years ($M = 19.05$, $SD = 1.26$) and with a mean education of 12.74 years ($SD = 0.88$), participated in this experiment. These participants were a subset of the young group in Experiment 1, and they completed the present experiment in the same sessions as the neuropsychological testing reported in Experiment 1. All were assigned z scores representing their relative performance on the two neuropsychological factors as outlined in Experiment 1. Those with factor scores above 0 were assigned to a high group, and those with scores below 0 constituted a low group on that function. FL factor scores ranged from −1.78 to 1.39 ($M = -0.08$, $SD = 0.60$), and MTL factor scores ranged from −1.90 to 1.19 ($M = -0.01$, $SD = 0.60$). All the young adults were undergraduates at the University of Arizona and received course credit for their participation. A comparison group of 24 older adults, also characterized on the basis of neuropsychological function, were selected from a larger pool of healthy, community-dwelling individuals over the age of 65 ($M = 72.4$, $SD = 2.06$) and received monetary compensation for their participation. Although the older group had significantly more years of education ($M = 16.3$, $SD = 2.4$) than the young group, $t(88) = 10.3$, $p < .01$, they did not differ from the young group on the two factor scores (both ts < 1). Their FL factor scores ranged from −1.59 to 1.02 ($M = -0.05$, $SD = 0.68$), and their MTL scores ranged from −1.39 to 1.49 ($M = 0.02$, $SD = 0.69$). Characteristics of the groups are summarized in Table 4.

Materials and procedure. The source and item memory tasks were identical to those described in Experiment 1 of Glisky et al. (2001), in which the item memory test involved memory for novel voices and the source memory test required remembering which of two studied sentences each voice spoke. Multiple male and female voices were recorded speaking two sentences that were equated for speaking time: "Stock prices fell sharply in heavy trading today, reflecting the uncertainty of the trade negotiations" and "Clouds are expected to move in from the west later this afternoon, increasing the likelihood of rain overnight." The voices and sentences were combined to form three 12-item lists composed of 12 voices (half male and half female) speaking one of the two sentences. Three additional 12-item lists were created in which each voice spoke the other of the two sentences. Each of the six lists occurred equally often across participants as targets for the item and source tasks and as distractors for the item test.

Table 4
Characteristics of Young and Older Adult Groups in Experiment 2

Characteristic	FL function		MTL function	
	High	Low	High	Low
Younger adults				
N	33	33	37	29
Age	19.0	19.1	19.0	19.1
Education	12.8	12.6	12.8	12.7
FL score	.39	−.55	.07	−.26
MTL score	.09	−.12	.40	−.54
Older adults				
N	12	12	12	12
Age	72.4	72.4	72.3	72.5
Education	15.9	16.7	16.5	16.1
FL score	.48	−.58	−.01	−.10
MTL score	.13	−.09	.56	−.52

Note. FL = frontal lobe; MTL = medial temporal lobe.

The source and item tests were matched for difficulty in younger adults. This matching was based on previous findings by Glisky et al. (2001) and also on additional pilot data indicating that in a sample of 32 younger adults, item and source memory performance did not differ significantly (74% and 75%, respectively). All study and test materials were presented with SuperLab on a Macintosh computer.

Two study-test sessions were conducted, with a brief digit cancellation distractor task between sessions. The item session always preceded the source session because pilot data indicated that under these presentation conditions, performance on the item and source tests was equated in young adults. In both sessions, participants were oriented to the voice (i.e., the item information), but no mention was made of a subsequent memory test or of its nature. For the item study, participants heard one 12-item list of voices each speaking one of the two sentences and were asked to rate on a 5-point scale how likely it would be to hear each voice on the radio. Study lists were presented three times to each participant in a different random order. Participants were then given a two-alternative forced-choice recognition test in which they were presented with two voices—a target voice from the study session and a novel distractor voice of a different gender. Target voices were never tested speaking the same sentence as at study, but always spoke the other of the two studied sentences. Thus, item memory depended solely on memory for the voice, not on the conjunction of voice and sentence. The distractor voice always spoke the other of the two studied sentences. Both sentences had thus been heard repeatedly during the study, whereas one voice of the pair had been studied and the other was novel. Participants were asked to decide which voice was heard during the study session and to respond by pressing the appropriate key (1 or 2) to indicate whether they had heard the first or second voice at study.

The source study was identical to the item study, except with a new list of 12 voices. The two-alternative forced-choice source recognition test immediately followed. Participants heard each studied voice speaking each of the two sentences that had been presented during the study session. Participants were asked to decide which of the two sentences was originally spoken by that voice and to respond by pressing the appropriate key (1 or 2). Note that in this case, the components of both the target and the distractor stimuli had occurred during the study, but only one of the voice–sentence combinations had been heard. In both the item and source tests, the target voice or sentence was presented first for half of the test items and second for the other half.

Results

Results for the young participants on the item and source memory tasks are presented in Table 5. The first thing to note is that, as expected on the basis of pilot data, performance on the item and source memory tasks was equivalent (.73 on source, .72 on item), confirming that the two tasks were of equal difficulty for young people. Second, performance on the two tasks was correlated in young adults, $r = .27$, $p = .03$, suggesting that young people may engage similar processes for item and source memory.

Of primary interest was the extent to which the FL factor scores predicted performance in source memory in young adults. A 2 × 2 between-groups ANOVA indicated that there was no effect of the FL factor scores on source memory, $F(1, 62) < 1$; high- and low-FL groups performed equivalently. There was, however, a significant effect of the MTL factor, $F(1, 62) = 4.26$, $MSE = 0.026$, $p = .04$. Those with above-average scores on the memory composite measure performed significantly better than those with below-average scores (.77 compared to .68). There was no interaction between the two factors. On the item memory task, there was no effect associated with the FL factor, $F < 1$. Overall the high-MTL group outperformed the low-MTL group, but that difference was not significant, $F(1, 62) = 1.63$, $MSE = 0.037$, $p = .21$, nor was there a significant interaction.

Results for the older group are shown in Table 6. A 2 × 2 between-groups ANOVA on the source memory data revealed a significant effect of FL factor scores, $F(1, 20) = 4.97$, $MSE = 0.023$, $p = .04$, indicating that the high-FL group (.69) performed at a higher level than the low-FL group (.56), replicating our earlier finding with a group of 32 older adults (high FL = .66; low FL = .54; Glisky et al., 2001). There was a nonsignificant effect of the MTL factor, $F(1, 20) = 2.45$, $p = .13$, and no interaction. There were no effects on the item memory task. In addition, item and source memory were not correlated in older adults, $r = -.007$, *ns*. Performance on the item memory task (.73) was significantly better than performance on the source memory task (.63), $t(23) = 2.29$, $p = .03$, suggesting that for some older adults, the source memory task was more challenging. A direct comparison between the two age groups confirmed a main effect of age in source memory, $F(1, 88) = 7.21$, $p = .01$, but no effect in item memory, $F < 1$.

Discussion

There was no hint that FL function as measured by our factor score played any role in the performance of young adults on the source memory task. This finding is in contrast to previous and present findings in older adults in which individuals with high FL scores have consistently outperformed those with low scores, indicating robust frontal involvement in source memory in older adults (Glisky et al., 1995, 2001). The finding also appears inconsistent with evidence from a number of neuroimaging studies that have implicated the FLs in source memory in young adults. There may be several reasons for these inconsistencies, given that the FLs are large, complex brain regions that likely support a myriad of control functions, only a small subset of which may be captured by our FL factor. One possibility, consistent with previous findings, is that the processes represented by our FL factor are involved in the initiation and/or execution of integrative processing during encoding. Such processes ensure that various, disparate aspects of an experience are linked together at encoding and are coregistered in the memory system so that they can later be simultaneously retrieved. Previous research (Glisky et al., 2001) has suggested that these kinds of integrative processes may be engaged automatically by young adults, without placing additional demands on frontal control processes. Older adults, on the other hand, may need to recruit control processes to ensure adequate integration of item and source information during encoding. Those older individuals who have above-average FL function may successfully recruit these processes, or they may, like young adults, be able to initiate and execute the integration processes spontaneously. Older adults with low FL function, however, may fail to initiate the processes necessary to achieve a well-integrated memory trace.

If integrative encoding processes are carried out rather automatically in young adults, individual differences among young people in source memory may reflect fundamental differences in less strategic aspects of memory processing, such as consolidation or binding, which depend more on the MTLs. Poor MTL function could result in deficits in both item and source recognition, although source memory would place greater demands on the binding process. The fact that item and source memory performance were correlated in young adults in Experiment 2 is consistent with shared processes across the two tasks. Note, however, that in older adults, item and source memory performance were not correlated, suggesting that the processes that older adults engage for the two tasks may be different.

There were also no significant benefits in item memory for those with high MTL function compared to those with low MTL function in either the young or old groups. Although we had previously obtained an effect of the MTL factor in older adults on item

Table 5
Proportion Correct on Source and Item Memory Tasks in Young Adults in Experiment 2

	Source memory task						Item memory task					
	High FL function		Low FL function		Mean FL function		High FL function		Low FL function		Mean FL function	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
High	.76	.14	.78	.20	.77	.16	.77	.16	.71	.17	.75	.17
Low	.68	.14	.69	.16	.68	.15	.61	.21	.74	.24	.69	.23
Mean	.73	.15	.73	.18	.73	.16	.72	.19	.73	.21	.72	.20

Note. FL = frontal lobe; MTL = medial temporal lobe.

Table 6
Proportion Correct on Source and Item Memory Tasks in Older Adults in Experiment 2

	Source memory task						Item memory task					
	High FL function		Low FL function		Mean FL function		High FL function		Low FL function		Mean FL function	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
High	.72	.13	.63	.12	.67	.13	.72	.13	.74	.16	.73	.14
Low	.67	.14	.49	.21	.58	.19	.72	.09	.72	.19	.72	.14
Mean	.69	.13	.56	.18	.63	.17	.72	.10	.73	.17	.73	.14

Note. FL = frontal lobe; MTL = medial temporal lobe.

memory with sentence materials (Glisky et al., 1995), in an earlier study of memory for voices (Glisky et al., 2001), we did not observe an advantage for the high-MTL group. Although the MTL factor score includes two nonverbal measures (with shapes and faces), it is possible that memory for novel voices relies on different processes than those required by most standard neuropsychological tests of memory (cf. Winograd, Kerr, & Spence, 1984).

Because the young adults appeared not to engage the frontal processes represented by our FL factor in this source memory task, we considered the possibility that the task was not difficult enough to require frontal input in young people. To test the difficulty hypothesis, we chose a more challenging source task in Experiment 3.

Experiment 3

In Experiment 2, the FL factor did not predict source memory performance in young adults. It has been suggested that the frontal lobes may be important only in difficult tasks. The source memory performance of younger adults in the previous experiment was .73, raising the possibility that this source task was not of sufficient difficulty to engage the FLs in young people. To rule out this possibility, a more challenging source task was chosen that required the participants to remember the spatial location in which each stimulus was presented (see Cook, 2007). In addition, an attentionally demanding neuropsychological test known to measure working memory was included in this experiment to ensure that the FL factor was sensitive to executive function differences in young adults.

Method

Participants. A group of 48 young adults, ranging in age from 18 to 22 years ($M = 18.73$, $SD = 0.96$) and with a mean education level of 12.7 years ($SD = 1.1$), participated in this experiment. Of these individuals, 30 were part of the larger group that participated in Experiment 1 but did not participate in Experiment 2. One of these participants was excluded for failing to follow instructions. An additional 19 young people, who were not part of either Experiment 1 or 2, were recruited from the same pool of psychology undergraduates, all of whom received course credit for their participation. All participants completed the present experiment during the same sessions in which their neuropsychological testing was conducted, and all were assigned *z* scores representing their performance on the two neuropsychological factors. FL factor scores ranged from −2.17 to 1.39 ($M = -0.001$, $SD = 0.67$), and MTL scores ranged from −0.94 to 1.29 ($M = 0.29$, $SD = 0.54$). Characteristics of this group are summarized in Table 7.

Materials and procedure. In this experiment, sentences served as the stimuli for the item test, and spatial location provided the source information. A male voice was recorded speaking 100 neutral sentences (e.g., "Yesterday she wrote an e-mail to me"). Five lists of 20 sentences were formed, with two lists serving as item study lists, two lists serving as distractors for the item test, and one list serving as the source study list, resulting in five counterbalancing conditions. Two study-test sessions were conducted. For 29 of the participants, the item session preceded the source session, as in Experiment 2. To ensure that order of tests did not influence the outcome, the remaining group of 19 individuals completed the source session prior to the item session. Sentences were presented auditorily, half from a speaker placed to the right of the individual and half from a speaker located to the left, and location varied randomly. For the item study task, participants heard 40 sentences presented once and were asked to rate on a 5-point scale how likely it would be to hear each sentence on the radio. Immediately following the item study, a two-alternative forced-choice recognition test was given in which participants heard two sentences, one that they had heard during study and one that was new, and they were asked to decide which sentence they had heard previously and to respond by pressing the appropriate key (1 or 2). For the source study session, 20 sentences were presented, and participants were asked to make the same likelihood judgment as in the item study session. The 20 sentences were presented twice in a different random order, but from the same speaker as in the first presentation. For the source test, participants

Table 7
Characteristics of Young Adults in Experiment 3

	FL function		MTL function	
Characteristic	High	Low	High	Low
N	24	24	32	16
Age	18.9	18.6	18.7	18.8
Education	12.9	12.5	12.7	12.8
FL score	.53	−.54	.15	−.32
MTL score	.46	.13	.61	−.33

Note. FL = frontal lobe; MTL = medial temporal lobe.

heard each target sentence played once from each speaker and were asked to choose from which speaker the sentence was originally presented and to respond by pressing the appropriate key (L or R). In both the item and source tests, the target sentence or location occurred first for half of the test items and second for the other half, and participants were not told ahead of time about the nature of the impending memory test.

Following the memory testing, the Paced Auditory Serial Addition Test (PASAT; Gronwall, 1977), a demanding working memory test, was administered to the initial group of 30 participants. A pseudorandom series of 61 numbers from 1 to 9 was presented auditorily with an audiocassette, with one digit presented every 2 s. Participants were required to add every two consecutive numbers and report each sum out loud.

Results and Discussion

There were no significant differences in performance on either the item or source memory tasks as a function of the order of testing, nor did this variable interact with either of the neuropsychological variables. Results were therefore collapsed across test order. Performance on the item memory test averaged 0.95 (SD = 0.07) and was on the ceiling in all groups; therefore, no further analyses were conducted with reference to the item memory data. Source memory performance, however, was quite poor (M = 0.54, SD = 0.11), attesting to the difficulty of the source memory task. Nevertheless, the distribution of scores on the source memory test ranged from .35 to .85, providing sufficient variability to assess the possible effects of our neuropsychological variables. Because the distribution of participants was unequal across cells of the design, however, the results were analyzed with both ANOVA and correlational measures.

The source memory data are presented in Table 8. A 2 × 2 between-groups ANOVA indicated that the only significant effect was for the MTL factor, $F(1, 44) = 8.76$, $MSE = 0.011$, $p = .005$, with the high-MTL group performing at a higher level than the low-MTL group. This significant effect is unlikely to be attributable to the below-chance level of performance of some participants, because the high-MTL group performed significantly above the chance level of .50, $t(31) = 3.88$, $p = .001$. A correlational analysis also showed that source memory was significantly correlated with the MTL factor, $r = .45$, $p = .002$, but not with the FL factor, $r = .10$, *ns*.

Table 8
Proportion Correct on Source Memory Task in Young Adults in Experiment 3

	FL function					
	High		Low		Mean	
MTL function	*M*	*SD*	*M*	*SD*	*M*	*SD*
High	.57	.11	.58	.10	.57	.11
Low	.48	.08	.47	.09	.48	.09
Mean	.55	.11	.53	.11	.54	.11

Note. FL = frontal lobe; MTL = medial temporal lobe.

The mean number correct on the PASAT was .56 (SD = .14), which is within the normal range for this age group (Strauss, Sherman, & Spreen, 2006), and PASAT scores were significantly correlated with the FL factor ($r = .47$, $p = .009$), indicating that our FL factor was sensitive to executive function differences in young adults when the working memory demands were high. Nevertheless, the executive processes tapped by the FL factor seemed not to be involved in the very difficult source memory task, again suggesting that our FL factor did not track difficulty.

General Discussion

Several interesting findings emerged from these experiments. First, the two-factor structure previously found in an exploratory principal components analysis in older adults was supported in a confirmatory factor analysis in a large sample of older adults and a large group of young college students. The analysis confirmed two factors, one composed of executive control and working memory tests thought to tap FL functions and one composed of memory tests associated with MTL functions. Somewhat unexpectedly, we found that neither college freshmen nor a group of more educated young adults differed significantly from older adults on our FL factor, either in mean level of performance or in variability. Although the young and older groups showed different relative strengths on the tests within the factor, the distributions of the composite FL scores were remarkably similar. These data thus indicate that although there are age-related declines in performance on individual FL tests, some aspects of executive function may hold up rather well with age, at least in a subgroup of older adults. The tests comprising the FL factor were selected on the basis of neuropsychological data suggesting that they tapped executive function. However, there are almost certainly numerous different executive processes associated with the FLs (see Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Stuss et al., 2002), and the literature is inconsistent with respect to the specific executive processes that decline with age. This inconsistency may be partly attributable to the variety of frontal tests used across studies and the unreliability of many tests of executive function (see Salthouse et al., 2003). In addition, most tests of executive function are not process pure and may require nonexecutive processes in addition to one or more executive processes (Crawford & Henry, 2005). Thus, it is difficult to attribute an impairment on any single frontal test to any particular executive function. The advantage of a composite measure derived from factor analysis is an increase in reliability because the factor represents the systematic variance shared by its constituent tests without measurement error. Scores on the composite measure thus reflect only the process or processes captured by that common variance. That variance in the present case is almost certainly traceable to the FLs given the evidence that each of the individual tests are associated with that brain region (e.g., Gerton et al., 2004; Gruber, Indefrey, Steinmetz, & Kleinschmidt, 2001; Konishi et al., 1999; Phelps, Hyder, Blamire, & Shulman, 1997). The factor analysis, however, cannot tell us what the common processes are or what specific neural correlates are shared. The data provided by the present study tell us only that the distribution of the processes associated with the FL factor score is similar across the age groups tested. However, experimental studies in which the factor is shown to be predictive of performance on other cognitive tasks may begin to provide suggestive evidence of the processes represented in the FL factor score.

The memory factor, however, did reveal lower performance in the older group, both in mean score and variability. Examination of the individual tests indicated that although the young adults scored significantly higher than the older adults only on the delayed test of visual paired associates, every test within the MTL factor showed a small numeric advantage for the young group. Nevertheless, the overall mean composite MTL score was not significantly different between the young and the older group, although the young group's scores were less variable. The memory factor score for the older young group, however, was significantly higher than that for both the young and the older groups, suggesting that memory function may continue to develop into the mid- to late-20s or with continuing education and may then decline in the upper years. There was also suggestive evidence of a similar pattern for the FL factor. Although differences between the older young group and the other groups on the FL composite were not significant (probably because of the smaller sample of older young people), performance on all five executive frontal tasks was numerically higher in the older young group than in the other two groups, suggesting that performance on these tests may also increase with age or education. We should note here that our older adult sample was highly educated (M = 15.6 years), although representative of many older adult samples reported in the literature, and so cognitive function may hold up particularly well in an educated group. Nevertheless, memory function was significantly lower in the older group relative to the education-matched older young group, suggesting that declines do occur in memory even in well-educated older adults.

The second finding of interest concerns the age-related differences in the involvement of the two neuropsychological composite measures in the source memory task. Previous research has made a strong case for the importance of FL function in source memory, although its exact role remains elusive. A few studies have also suggested that older adults use different processes than young adults to perform source memory tasks, but how and why these processes might differ is unclear. The present studies provide further evidence relevant to this issue. Our previous work (Glisky et al., 2001) indicated that older adults with below average scores on the FL factor failed to integrate item and source during encoding, although when given an integrative encoding task, they were able to integrate item and source and benefit from that integration. More recent studies from our lab (Cook, 2007) have shown that low-FL older adults do not integrate information from two different sources, although young and high-FL older adults are quite able to do so. These findings have led us to propose that the FL factor may reflect a component of working memory that enables the integration of information across different cognitive or perceptual domains. These processes may decline in a subgroup of older adults but remain intact in others. Neuroimaging evidence consistent with this view comes from a study by Mitchell, Johnson, Raye, and D'Esposito (2000a), who reported that young adults showed greater activation in the right anterior PFC (BA 10) and the left anterior hippocampus in a working memory task when encoding combinations of objects in locations than when encoding either objects or locations alone. Older adults, however, failed to activate these regions and showed a selective memory deficit for the conjunction of object and location. These investigators attributed this failure to an age-related binding deficit in older adults that reduced their ability to integrate multiple features of an experience. Our findings suggest that this integrative process may be particularly affected in older adults with below average scores on our composite measure of FL function.

Alternatively, the deficit in source memory in our low-FL older group could be attributable to a failure to initiate the encoding and/or retrieval processes necessary for good performance in source memory tasks (cf. Craik, 1986) rather than a deficit in integrative processing per se. Craik and Byrd (1982) have suggested that a general decline in processing resources with age could underlie a number of age-related declines in memory. Older adults with good executive function may have more of these resources or may be more likely to recruit them in a compensatory fashion for difficult memory tasks, whereas those with poorer executive function may be less able to do so. Our previous findings, showing that our FL factor scores were not predictive of performance in a difficult and demanding item memory task, however, suggest that our FL factor score is not just a measure of a general processing capacity, but may reflect processes, such as integration, that are more specific to source memory. Related work by Naveh-Benjamin and colleagues (e.g., Naveh-Benjamin, 2000) also has suggested a differential deficit in associative memory in older adults, compared with memory for the individual items forming the association. These investigators (Naveh-Benjamin, Guez, & Shulman, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) have provided additional evidence that the associative deficit is not attributable simply to declining processing resources in the older group: Young adults with reduced processing resources (i.e., under divided attention conditions) did not show a differential deficit in associative memory. These findings are consistent with our proposal that the deficit in source memory observed in our low-FL group reflects a specific problem with integrating item and source information in working memory. Our view is also similar to one proposed and modeled by Kimberg and Farah (1993; also Kimberg, D'Esposito, & Farah, 1997), who suggested that prefrontal damage in patients weakens the strength of associations among elements in working memory, causing failures on multiple executive tasks, including WCST, for example, one of the tasks in our frontal composite (see also Spencer & Raz, 1995).

The FL effect, however, was not observed in young people. This suggests that the source memory task in young people does not require the control processes tapped by our FL factor. Young people may not need to engage FL support to integrate disparate components of an experience during encoding; such integration may occur spontaneously and without demands on attentional resources (cf. Naveh-Benjamin et al., 2003, 2004). Thus, although the FL factor may reflect a capacity-limited function of working memory, this capacity may not be taxed by source memory tasks in young people. The FL factor appears to be sensitive to working memory differences in young adults, however: When presented with an attentionally demanding working memory task, such as the PASAT, young people with lower FL factor scores exhibited lower levels of performance.

An alternative explanation for the lack of an FL effect in young adults may be that the two-alternative forced-choice recognition test does not require executive control processes, whereas a cued recall test might. We think this is unlikely to be the case. The high degree of familiarity of the lures in the two-alternative forced-choice source task suggests that this task requires recollective processes to retrieve the particular conjunction of item and source, and such processes would likely overlap those required in cued recall. In addition, although different test formats also have different processing requirements (e.g., cued recall has a search component that may be absent in recognition), it is not obvious that these two test formats would make different demands on the kinds of working memory processes that seem to characterize our FL factor. Other executive function tasks may provide better indicators of retrieval processes. Nevertheless, it is possible that different test formats could be differentially sensitive to our factor scores, and we are currently investigating this possibility.

Whether high-FL older people perform the integrative functions automatically as young adults appear to do or whether they initiate compensatory strategies to integrate the multiple aspects of an event cannot be determined from the present experiment. Future neuroimaging studies, however, could serve to clarify whether the processes in the high-FL older group are similar to those in young group or whether they involve the recruitment of additional brain regions. Such a study is currently underway in our laboratory.

The finding of a significant MTL effect in young adults was an unexpected result. We speculate that, although different aspects of an experience may be coded and integrated automatically during encoding in young people, these components still have to be bound together by structures in the MTLs. For item recognition, relatively little binding is required, and so effects of low MTL function may be minimal. The retrieval of source information, however, places greater demands on binding; therefore, MTL function is likely to be more important for source memory. Consistent with this notion, the findings of Mitchell, Johnson, Raye, and D'Esposito (2000) indicated that in young adults, the hippocampus showed greater activations during the encoding and maintenance of object–location conjunctions than for either object or location alone. Similarly, Davachi, Mitchell, and Wagner (2003) found that MTL activations were involved in the encoding of both item and source, with the hippocampus and parahippocampal cortex associated with subsequent source recollection and with the perirhinal cortex associated with item recognition. These findings suggest that low scores on our MTL factor may thus reflect poorer binding at the level of the hippocampus. If this is the case, one might also expect to see an effect of MTL function on source memory in older adults. Although we have generally not found such an effect, there was a nonsignificant advantage for the high-MTL older group in the present study, and such a finding has been previously reported in the literature by other investigators (e.g., Henkel et al., 1998).

One other finding is of particular note: Performance on the item and source memory tasks in Experiment 2 was correlated ($r = .27$) in young adults but not in older adults. At first blush, this finding seems to suggest that young adults may use similar processes when performing the two tasks, whereas older adults do not. This conclusion, however, seems contrary to the neuroimaging data, which shows that younger adults activate the right PFC for item recognition but recruit the left PFC when recollection of additional details is necessary (e.g., Dobbins et al., 2002; Mitchell et al., 2004; Nolde et al., 1998). It may be that young people, although engaging different regions of PFC in the two tasks, nevertheless access the same integrated memory representation when making either item or source memory judgments, thereby accounting for the correlation. Results of fMRI studies by Gold et al. (2006) showed similar activations in MTL regions during both item and source memory tests and are consistent with this view.

Older adults, on the other hand, may not access the memory trace when faced with the resource-demanding source memory task; instead, they may attempt to base their source judgments on familiarity. This failure to engage in recollective processing may be particularly likely to occur in low-FL older adults, thereby contributing to their poor performance in source memory. Alternatively, they may access an impoverished memory trace, which is sufficient to support item memory but lacks the details to support source memory. Another possibility is that older adults recruit the same processes as young adults for source memory tasks, but they are less efficient. Findings consistent with this view were obtained in a neuroimaging study of source memory (Cabeza, Anderson, Locantore, & McIntosh, 2002), in which it was reported that some older adults activated the same right unilateral prefrontal regions as young adults, but nevertheless performed more poorly. Other older adults activated prefrontal brain regions bilaterally and showed levels of performance comparable to the young adults. These results suggest that the processes used by the poor performers, although apparently similar to those used by young adults, were ineffective. The high performers, on the other hand, appeared to recruit additional processes to maintain a high level of performance.

From the present study, it is unclear exactly how to interpret the lack of correlation among the two tasks in older adults. On the one hand, it might represent the recruitment of additional resources or alternate processes required to maintain high levels of performance on the more demanding source memory task. On the other hand, it might represent a failure of recollective search and monitoring processes needed to retrieve source-specifying information or the lack of source information in the memory trace. Answers to this question will thus require further neuroimaging studies in young and older adults to help identify the specific processes required by source memory tasks at both encoding and retrieval and the differences that exist both between young and old adults and between different subgroups within the older cohort.

Finally, there is an apparent discrepancy between the neuropsychological and neuroimaging findings. Neuroimaging data have frequently shown PFC activations in young adults in source memory tasks, but in the present studies, FL function seemed not to be implicated in young people. Most of the neuroimaging studies, however, have focused on retrieval, whereas we propose that the FL effect that we have observed occurs at encoding. The neuroimaging study by Mitchell, Johnson, Raye, and D'Esposito, (2000a), however, showed right PFC activation during integrative encoding of item and source in young adults but not in older adults, a result that seems contrary to the current findings. However, activation in BA 10 may reflect integration processes per se or may track maintenance of integrated information (see Prabhakaran et al., 2000), and this activation may be present whether the integration occurred spontaneously or with effort. As we have argued previously, integration processes are initiated spontaneously by younger adults and do not require input from the executive control processes reflected in our FL factor. Older adults with low FL function may fail to initiate the integrative processes entirely. We would therefore hypothesize that older adults who are low performers on our FL composite would not show activation of this

PFC region during source encoding, whereas high-FL older adults and young people would. Again, whether high-FL older adults do this spontaneously or whether they recruit additional resources cannot be determined from the present data.

In summary, the present studies have added to our knowledge of the processes involved in source memory in young and older adults. Findings are consistent with a specific deficit in integrative encoding processes among older individuals who had below-average FL function on our composite measure. Although we hypothesize that the FL composite reflected attentional or executive processes associated with working memory in both young and older adults, the integrative processes required by the source memory tasks in these studies did not appear to tax working memory in young people. Instead, deficits in source memory occurred in young adults with low MTL function and may have been attributable to less effective binding mechanisms in the hippocampus. Older adults may also have had a more general problem with the initiation of relevant encoding and retrieval processes, and their strategies may have been less efficient. Recruitment of additional executive functions thus may be needed when encoding or retrieval processes are poorly supported by the task environment.

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