Psychonomic Bulletin & Review
2007, 14 (4), 606-611

Brief Reports

The effects of frontal lobe functioning and age on veridical and false recall

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Older adults' heightened susceptibility to false memories has been linked to compromised frontal lobe functioning as estimated by Glisky and colleagues' (Glisky, Polster, & Routhieaux, 1995) neuropsychological battery (e.g., Butler, McDaniel, Dornburg, Price, & Roediger, 2004). This conclusion, however, rests on the untested assumption that young adults have uniformly high frontal functioning. We tested this assumption, and we correlated younger and older adults' frontal scores with veridical and false recall probabilities with prose materials. Substantial variability in scores on the Glisky battery occurred for younger (and older) adults. However, frontal scores and age were independent contributors to recall probabilities. Frontal functioning is not the sole cause of older adults' heightened susceptibility to false memories.

Conventional wisdom tells us that older adults are forgetful, and this claim is generally corroborated by empirical evidence (Kausler, 1994). Older adults are also more prone to remembering events that did not happen. For example, compared with younger adults, older adults are more likely to remember misleading postevent information as having occurred in the original event (Multhaup, De Leonardis, & Johnson, 1999; Roediger & Geraci, 2007); they are also more likely to identify a familiar name as belonging to a famous person (Dywan & Jacoby, 1990). Moreover, after studying semantic associates (e.g., bed, rest, awake) of a nonpresented word (e.g., sleep) in the Deese/Roediger–McDermott (DRM, Roediger & McDermott, 1995) protocol, older adults are more likely than younger adults to recall or recognize the nonpresented word (Norman & Schacter, 1997).

The neural underpinnings of age-related memory deficits are not entirely clear, although recent empirical evidence suggests that the frontal lobes play an important role. Degradation in the frontal lobes occurs with aging (Anderson & Craik, 2000; West, 1996), and the frontal lobes are particularly susceptible to volumetric reduction as a person ages (Buckner, 2004; Raz, 2000). Because the frontal lobes are implicated in processes such as source monitoring (Henkel, Johnson, & De Leonardis, 1998), declines in frontal lobe functioning might reduce an older adult's ability to avoid false memories. A corollary of this idea is that older adults who do not show age-related frontal deficits may exhibit memory performance similar to that of younger adults. We will refer to this concept as "the frontal hypothesis" of age-related memory deficits. In the current experiment, we put a strong form of this frontal hypothesis to test. Specifically, are age-related changes in frontal functioning the primary, or sole, cause of age-related increases in false memories?

Glisky and her colleagues described a neuropsychological battery intended to estimate the level of frontal/executive functioning for healthy older adults (Glisky et al., 1995). Using the aforementioned DRM paradigm, Butler and colleagues (2004) demonstrated that older adults with low frontal functioning as indicated by scores on this neuropsychological battery are more susceptible to false memory than older adults with higher frontal functioning. Specifically, low-frontal older adults recalled fewer studied words and more nonpresented associates (e.g., sleep) than did younger adults or high-frontal older adults. However, recall performance of the latter two groups did not differ.

Results from this study suggest that age-related differences in accurate and false recall are mediated by age-related differences in frontal functioning as estimated by the Glisky battery (Butler et al., 2004). A second finding highlighted in the article was that age-related deficits in memory performance were minimal or nonexistent among older adults with high frontal functioning, leading to the conclusion that "declines in veridical recall and increases in false recall are not an inevitable consequence of aging" (Butler et al., 2004, p. 921). That is, although age-related differences in false recall were obtained, "this pattern held only for older adults who performed poorly on a battery of tests that have been related to FL [frontal lobe] function" (p. 924).

To our knowledge, the frontal battery developed by Glisky et al. (1995) has been administered only to older

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Table 1
Demographic Characteristics and Memory Performance of Younger and Older Adults

Demographic Characteristic	Younger (*n* = 60)		Older (*n* = 59)	
	M	*SD*	*M*	*SD*
Age (years)	19.77	1.45	74.51	4.59*
Years of education	14.33	1.10	15.31	2.48*
Shipley vocabulary score	–	–	35.56	3.14
Frontal battery score	.19	.51	−.18	.67*

*Comparison between the means for younger and older adults is significant at $p = .05$.

adults in all published studies; younger adults have been assumed, either implicitly or explicitly, to have a high level of frontal functioning (e.g., Butler et al., 2004; Davidson & Glisky, 2002). For example, consider the claim by Butler et al. (2004) that "high frontal lobe functioning older adults and young adults had equivalent levels of false recall, as well as equivalent levels of veridical recall. These results suggest that age differences in memory may be due to declines in frontal lobe function" (p. 921). The assumption underlying this statement is that young adults have high frontal functioning and that low frontal older adults have declined over time.

We formally tested this assumption by administering the frontal battery to both younger and older adults. Going into this experiment, it was unclear whether the frontal battery would be effective at capturing the variability in younger adults' frontal functioning. One concern was that the battery is not sensitive enough to pick up such variability among generally high-functioning, college-attending younger adults. To preview, the frontal battery was indeed an effective classification tool for younger adults.

Regression analyses were conducted to examine the effects of age and frontal functioning on probabilities of veridical and false recall. In addition, we used a different false memory protocol to examine the hypothesis that age-related increases in false memories can be attributed to declines in older adults' frontal functioning. In this experiment, participants read sentences embedded with pragmatic implications and later performed a cued recall test on these sentences. For example, "The karate champion hit the cinder block" pragmatically implies that the cinder block was broken, although this outcome is not explicitly stated in the sentence. The effectiveness of such sentences in eliciting false memories is well-documented (Brewer, 1977; Chan & McDermott, 2006; Johnson, Bransford, & Solomon, 1973), and these materials are well-suited for research on aging because they capitalize on the dissociation between older adults' preserved semantic memory/comprehension ability and impaired episodic memory/surface level recall (McDermott & Chan, 2006).

METHOD

Participants

The younger adults ($n = 60$) were undergraduate students at Washington University who either received course credit or were paid $10 for their participation in a one-hour study that included the pragmatic inference experiment and the frontal battery. The older adults ($n = 60$) were recruited from the Washington University Psychology Department's older adult volunteer pool. Older adults were paid $30 to participate in a three-hour multiexperiment study and the pragmatic inference experiment was conducted during the third hour of the experimental session (participants were given ample rest breaks after each hour of participation). Older adults completed the frontal battery within the 12 months prior to the experiment. Although this delay was not optimal, logistical considerations precluded testing the older adults sooner. Younger adults completed the frontal battery following the pragmatic inference experiment. One older adult was excluded from all analyses as an outlier;[1] therefore, results were based on the remaining 59 older adults. Table 1 presents mean age and years of education of the participants. It also shows scores on the Shipley Vocabulary Test (Zachary, 1986) for the older adults. This information was not collected for the younger adults.

Materials and Procedure

The frontal battery included five measurements, which were the number of categories completed in Modified Wisconsin Card Sorting (Hart, Kwentus, Wade, & Taylor, 1988), scores on FAS Phonemic Fluency (Spreen & Benton, 1977), Mental Arithmetic from the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981), Mental Control and Backward Digit Span from the Wechsler Memory Scale III (WMS-III, Wechsler, 1997).

Frontal scores were computed by taking the average of the five component tests scores standardized on the total sample. We used a simple average of the *z* scores instead of age-adjusted average *z* scores as described in Glisky et al. (1995) for the following reasons: (1) Glisky and colleagues used age-adjusted scores probably because they had only older adults in their experiments, and (2) using age-adjusted scores to compute the frontal scores would heavily underestimate the frontal performance of younger adults. In fact, the equations provided by the Glisky lab (age-adjusted scores) classified 58 of the 60 young adults in the current experiment as low frontals.[2]

To measure recall performance, we used the same pragmatic inference sentences as presented in McDermott and Chan (2006). The 48 sentences were separated into three sets of 16 sentences each for counterbalancing purposes. One set was presented once, one set was presented three times, and one set was withheld during study (new sentences). Both younger and older participants studied 32 unique sentences in a total of 64 trials (16 sentences presented once and 16 sentences presented thrice) and then received a paper-and-pencil cued recall sentence fragment test. The sentence fragments left the critical information blank, and participants were asked to recall the missing part word-for-word and to avoid guessing. In addition, participants were instructed to circle "Forget" if they could remember having studied the sentence but were unable to recall the missing part *word-for-word*, and they were told to circle "New" for nonstudied sentences. The following is a test sentence as seen by a participant:

The karate champion ______ the cinder block. Forget New

Each sentence was shown for 3.5 sec on the computer screen during the encoding phase. Participants were then given 20 min to complete the written test at their own pace. They were told to complete the test in the order in which the test sentences were printed and were warned against returning to a previously completed test sentence.

RESULTS

Scoring procedures were similar to those used by McDermott and Chan (2006). Responses were classified into five categories: (1) *Correct* for verbatim responses, although synonyms, tense, and singular-plural form switching were acceptable, (2) *false* for pragmatic inferences, (3) *other*

Table 2
Glisky Battery and Memory Performance of Younger and Older Adults in High and Low Frontal Groups

	Younger				Older			
	High (n = 39)		Low (n = 21)		High (n = 25)		Low (n = 34)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Frontal battery score	.46	.37	−.34	.31	.42	.27	−.63	.50
Accurate recall	.38	.16	.26	.12	.32	.13	.20	.14
False recall	.30	.15	.38	.13	.40	.14	.50	.14
Forget	.25	.14	.23	.14	.17	.15	.17	.14
Other	.03	.05	.06	.06	.06	.05	.06	.06
Miss rate (claim "new")	.04	.05	.06	.06	.04	.05	.07	.07
Correct rejection of new sentences	.97	.08	.96	.07	.94	.11	.85	.18

for responses that did not fit either the correct or false categories, (4) *forget*, and (5) *new*. To keep scoring criteria consistent across all sentences, we identified specific responses that would be accepted as pragmatic inferences for each sentence a priori. For example, the responses that were classified as a pragmatic inference for "the karate champion" example were "broke" and "smashed." If, for example, a participant recalled "kicked," it was scored *other*.

Preliminary analyses indicated that the patterns of accurate and false recall data were similar for one and three study presentations; therefore, number of presentations was collapsed for all analyses to increase power. To facilitate comparison with previous studies, Table 2 shows the means of recall probabilities for younger and older adults separated by their level of frontal functioning. Classification of younger and older adults into the high and low frontal groups was based on a mean-split of the Glisky battery scores on the entire sample. That is, a participant who scored below the mean of the entire sample (that is, zero in *z*-score) would be classified as low frontal regardless of his/her age. Simultaneous regression analyses were conducted to examine the relation between age and frontal functioning with accurate and false recall. The bivariate correlations are displayed in Table 3. Standardized regression coefficients (β weights) reflect the unique contribution of each independent variable. Significance level was set at $p < .05$ unless otherwise noted.

The first regression analysis examined the relations between age, frontal scores, and accurate recall. This analysis showed that age and frontal scores accounted for a combined 21% of the variance in accurate recall, R = .46 [$F(2,116) = 15.38$]. The negative correlation between age and accurate recall ($r = -.28$) demonstrates that accurate recall decreased with age.[3] The positive correlation between frontal scores and accurate recall ($r = .43$) indicates that higher frontal scores were associated with higher probability of accurate recall (see scatterplot in Figure 1A). Importantly, both age and frontal scores accounted for unique variance in accurate recall probabilities—the β for age was marginally significant at −.16 [$t(118) = 1.85$, $p < .10$], and the β for frontal scores was .38 [$t(118) = 4.40$]. Moreover, age and frontal scores did not interact ($F < 1$). This lack of interaction suggests that the relation between frontal scores and accurate recall did not differ between younger and older adults.

More important for the current purposes are the results for false recall. Specifically, age and frontal scores accounted for approximately 20% of the variance in false recall, $R = .45$ [$F(2,116) = 14.33$]. The positive correlation between false recall and age ($r = .39$) suggests that false recall probabilities increased with age, whereas the negative correlation between false recall and frontal scores ($r = -.33$) indicates that higher frontal scores were associated with lower probabilities of false recall (see Figure 1B). An examination of the regression coefficients indicated that age [$\beta = .46$, $t(118) = 3.62$], and frontal scores [$\beta = -.23$, $t(118) = 2.64$] accounted for unique variance in false recall probabilities. Moreover, similar to the data for accurate recall, age and frontal scores did not interact ($F < 1$). This lack of interaction, again, suggests that the relation between frontal scores and false recall did not change with age.

The regression coefficients indicate that both age and frontal scores accounted for unique variance in false recall probabilities. To more directly put the frontal hypothesis to test, a hierarchical regression analysis was conducted. If the frontal functioning account is correct, then once the variance in recall that is associated with frontal scores has been removed, age should no longer account for any remaining variance in recall. Contrary to this prediction, age *did* account for a significant additional proportion of the variance in accurate recall (2%, $F_{change} = 3.42$) and false recall (9%, $F_{change} = 13.07$) after the variance associated with frontal scores had been removed.

One may wonder whether the age-related differences in recall were carried by older adults who had very low frontal scores and younger adults who had very high frontal scores, as no younger adult in the current sample scored under −1.2 and no older adult scored over 1.0 (and because

Table 3
Bivariate Correlations for Age, Frontal Scores, Accurate Recall Probabilities, and False Recall Probabilities

	Age	Frontal Score	Accurate Recall	False Recall
Age	–			
Frontal score	−.31*	–		
Accurate recall	−.28*	.43*	–	
False recall	.39*	−.33*	−.53*	–

*$p < .05$.

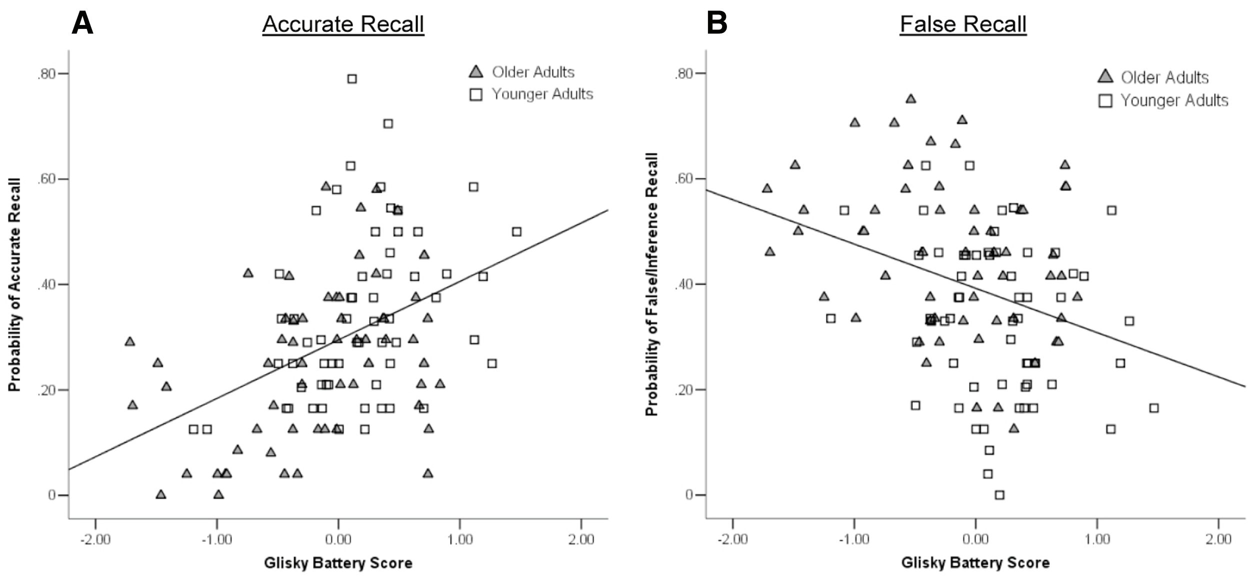

Figure 1. Scatterplots showing the probability of accurate (A) and false (B) recall as a function of frontal functioning.

the average frontal scores were lower among older adults). To that end, we examined whether the same age-related deficits appeared if we examined only individuals whose frontal scores overlapped by eliminating older adults on the lower end and younger adults on the higher end of the frontal score distribution. The relation remained: Eliminating these extreme individuals made no difference to our conclusions.

DISCUSSION

Two interesting findings emerged from this study. First, the assumption that college students have uniformly high frontal function is incorrect. Second, frontal functioning and age accounted for *unique* variance in accurate and false recall. A hierarchical regression analysis showed that even after frontal functioning had been accounted for, robust age differences in false recall remained. This finding suggests that age-related differences in frontal functioning is not a sufficient explanation of reduced accurate recall and increased false recall in later life. We now consider the significance of these results in more depth.

One major purpose of this study was to test the assumption that all college-attending young adults have high frontal functioning; specifically, we examined whether the Glisky battery would fail to pick up substantial variability in performance among young adults. Not only did the frontal battery pick up sufficient variance in young adults' frontal scores, these frontal scores were effective in predicting the levels of veridical and false recall among young adults. In fact, the finding that higher frontal functioning in young adults is associated with lower levels of false recall is consistent with an emerging literature on the relationship between working memory capacity and false recall in younger adults (e.g., Jaschinski & Wentura, 2002; Rhodes & Kelley, 2005; Watson, Bunting, Poole, & Conway, 2005). Because areas in the frontal lobes are critical to executive functions such as working memory capacity, these studies along with our data suggest that like older adults, younger adults' susceptibility to false memories may also be driven by their level of frontal functioning.

Although the frontal battery seems to be a valuable classification tool for both younger and older adults, it is obviously an indirect measure of frontal lobe function at best (although neuroimaging studies that have investigated some of the component tests used in the Glisky battery revealed activation in the frontal lobes, particularly regions within the prefrontal cortex [Cabeza & Nyberg, 2000; Hoshi et al., 2000; Smith, Taylor, Brammer, & Rubia, 2004; Warburton el al., 1996]). Indeed, these tests may better be viewed as measurements of executive control. As Jacoby (1991) has argued, no task is process pure; by the same token, no task is brain-region pure, either. The frontal scores obtained from this neuropsychological battery are not meant to represent the level of frontal functioning in any pure form. Brain regions other than those within the frontal lobes are undoubtedly involved as well. Regardless of the exact processes that the Glisky battery measures, to the extent that it taps some of the component processes or neural networks that are responsible for the recall task, frontal scores and recall probability should, and did, correlate.

Why should scores on the frontal battery correlate with accurate and false recall performance in the current paradigm? Accurate recall in this paradigm requires verbatim retrieval of words presented during the encoding episode and rejection of the pragmatic inference that can come to mind during retrieval. Such retrieval operations, as we have indicated elsewhere (McDermott & Chan, 2006), require recollective, controlled retrieval of the studied materials, which have been shown to correlate with frontal functioning based on both neuropsychological (e.g., Davidson & Glisky, 2002) and functional neuroimaging (e.g., Velanova et al., 2003) evidence.

The lack of an interaction between age and frontal functioning on the level of false recall suggests that the relation between frontal functioning and false recall remains relatively stable in adulthood (although we did not include middle-age participants in this experiment, but see Lovden, 2003). If this is the case, then what is driving the age-related difference in recall performance when frontal functioning has been accounted for? One obvious possibility is that age-related changes in other brain regions also contribute to age-related differences in recall. After all, regions in the medial temporal lobe are critically important to memory encoding and retrieval and these regions also display significant age-related degradation (Raz, 2000). Another possibility is that differences in processing speed (Salthouse, 1996) between younger and older adults might have contributed to differences in their recall performance. This possibility is very real especially when one considers that the encoding time was the same for younger and older adults (cf. McDermott & Chan, 2006). One more possibility is that younger adults and high-frontal older adults approach an episodic memory task (or even the frontal battery, as suggested by their different loadings patterns as described in note 2) with different strategies, even if they are equally capable in their frontal functioning as estimated by the Glisky battery (Cabeza, Anderson, Locantore, & McIntosh, 2002; Logan, Sanders, Snyder, Morris, & Buckner, 2002). Functional neuroimaging studies that correlate neuropsychological measures, age, behavior, and activity within specific regions of frontal cortex (and other brain regions) hold particular promise for shedding light on these issues (e.g., Cabeza et al., 2002).

Our findings suggest that the Glisky battery is effective in identifying the individuals who might be more susceptible to false remembering and reveal that this relation applies to younger adults, too. Our findings also suggest that the story that "frontal functioning accounts for age-related differences in false memories" is incomplete. How specific brain regions within and beyond frontal cortex act in concert to modulate the likelihood of false memories will surely be a fruitful topic of future research.

AUTHOR NOTE

We thank Jane McConnell and Pooja Agarwal for their assistance with participant testing, and we thank Roddy Roediger, Mark McDaniel, Dave McCabe, Lisa Geraci, Sean Kang, Karl Szpunar, Jason Watson, Keith Lyle, and Alan Castel for their helpful discussions. The first author would also like to express his gratitude to Martha Storandt for her tireless support, statistical advice, and theoretical discussion throughout this project. Correspondence concerning this article should be addressed to J. C. K. Chan, Department of Psychology, Iowa State University, Ames, IA 50011-3180 (e-mail: jasonckchan@gmail.com).

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NOTES

1. The subject was revealed as an outlier through regression diagnostics. Specifically, this person's data was classified as an outlying influential data point; the subject's Cook's Distance on accurate recall was .30, whereas the mean of all 60 older adults was .02. Similarly, this subject's Cook's Distance on false recall was .26 whereas the mean was .02. We note, though, that if we had included this outlying data point, it would not have changed any of our conclusions.

2. We also subjected the five component test scores to a factor analysis, which yielded a single factor. Using this factor score as the frontal score did not change any of our conclusions. Spearman's rho rank-order correlation was computed to compare older adults' frontal scores created by our method and by Glisky's equations. The correlation ($r = .98$) indicated that scores created by the two methods were highly comparable, at least for older adults. In addition, another factor analysis was conducted to examine factor loadings separately for younger and older adults. Interestingly, the five subtests in the Glisky battery loaded on two factors for the younger adults but only one factor for the older adults. For the younger adults, the loadings on the first factor for WCST, FAS, arithmetic, mental control, and digit span were .06, .48, .75, .77, and .49, respectively. Loadings on the second factor were .81, −.57, .02, .08, and .32 (in the same order). On the other hand, for the older adults, the loadings on the factor were .35, .74, .76, .73, and .73. Although the five subtests loaded on two factors for younger adults and only one factor for older adults, the factor loadings on the first factor showed a similar pattern for the two subject groups. In particular, the WCST loaded differently on the first factor than the other subtests. This suggests that the WCST might have tapped different mental processes than the other subtests, although the exact nature of this difference is unknown. Furthermore, the fact that results of the factor analysis differ between subjects in the two age groups suggests that younger and older adults might have approached the frontal battery with different strategies.

3. Some researchers (e.g., Bryan & Luszcz, 1996) have suggested that when a bimodal distribution (as in age in the present experiment) is used in a regression analysis, dichotomizing the variable reduces the impact of extreme groups (e.g., younger adults = 1, older adults = 2). We conducted all the regression analyses (including the hierarchical regression analyses) using age group as an independent variable, and all of the conclusions emerging from our regression analyses remain the same.

(Manuscript received May 15, 2006;
revision accepted for publication October 4, 2006.)