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An fMRI investigation of short-term source memory in young and older adults

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Using functional magnetic resonance imaging (fMRI) and a working memory procedure, we compared source memory judgments (format and location) with old–new judgments in young and older adults. Consistent with previous fMRI findings, for young adults, an area of left dorsolateral prefrontal cortex showed greater activity during format than old–new judgments made immediately, as well as those made after a brief, filled delay. In contrast, for older adults, activity in this area was not greater during format than old–new judgments at either retention interval. These data provide additional evidence that left lateral prefrontal cortex is important in monitoring specific source information and new evidence that older adults' source memory deficits may be related, in part, to reduced function of this brain area.

Source memory refers to memory for details that collectively make up an event and that help differentiate it from other events (Johnson et al., 1993). Such details may be actually experienced or inferred, and may include perceptual information like color or size, spatio-temporal details, how we felt or what we thought at the time, and so on. Such memory (sometimes referred to as memory for context, though source memory is a broader concept) is often contrasted, both theoretically and empirically, with item memory (e.g., "Did you see this?" vs. "Where did you see this?"). Item memory tends to rely on less differentiated information, such as familiarity or recency (see Mitchell et al., 2004, for a more thorough discussion). Compared to young adults, older adults often show disproportionate deficits in long-term source memory relative to item memory in episodic memory tasks (e.g., Simons et al., 2004; Wegesin et al., 2000; see, e.g., Johnson et al., 1993; Spencer and Raz, 1995 for reviews).

Behavioral evidence suggests that this age-related difference in source memory reflects, in part, age-related deficits in monitoring (i.e., reviving and evaluating) mental experiences during remembering. Such monitoring includes weighting features differentially during revival and evaluation of information (i.e., "looking for" certain information, and assessing how important any revived information is) (Johnson et al., 1993). Older adults are less likely to spontaneously access or consider available source-specifying information (Koutstaal, 2003; Multhaup, 1995; Rahhal et al., 2002), especially when multiple sources of information are involved (e.g., Johnson et al., 1995; Mitchell et al., 2000b, Experiment 2), and they may weight information differently in terms of its diagnosticity (e.g., Johnson and Multhaup, 1992; Mitchell et al., 2003). Such deficits are consistent with anatomical, neuropsychological, and neuroimaging evidence of age-related changes in the structure and function of the prefrontal cortex (PFC; e.g., Cabeza et al., 2002; Craik et al., 1990; Glisky et al., 1995; Golomb et al., 1996; Grady, 2000; Henkel et al., 1998; Mitchell et al., 2000a,b; Moscovitch and Winocur, 1995; O'Brien et al., 1997; Raz, 2000; Small et al., 2002; West, 1996). Reflective attentional/executive processes subserved by prefrontal cortex (PFC) are important for monitoring information during remembering. In particular, several long-term source memory studies with young adults have reported left lateral PFC activity associated with source memory judgments (e.g., Dobbins et al., 2002; Dobbins et al., 2003; Henson et al., 1999; Nolde et al., 1998a; Ranganath et al., 2000; Raye et al., 2000; Rugg et al., 1999; Slotnick et al., 2003). Such activity presumably reflects monitoring specific information important for making accurate source memory judgments (e.g., Johnson et al., 1993). Together, age-related behavioral deficits in source memory, evidence of age-related changes in PFC, and neuroimaging findings linking activity in left PFC to source memory suggest that we should find evidence of disrupted source-related activity in left lateral PFC in older adults.

Recently, we used a short-term source memory task in an fMRI study with young adults to investigate monitoring specific information (format and location judgments) vs. less-differentiated information (old–new recognition) (Mitchell et al., 2004). To maximize the likelihood that information was in working memory, and thereby minimize the need for revival of information from long-term memory, each trial presented only four items seen sequentially for 1 s each: two pictures, two words, one of each on the left of the screen and one of each on the right. A single word

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was presented immediately after the last study item to probe for either the format of the target item (picture, word), the location of the target (left, right), or old–new recognition. Thus, trials differed only in the type of test. For any given trial, participants did not know what kind of test they would receive and trials were randomly intermixed to equate encoding across test types. As in long-term memory studies, we found greater left lateral PFC activation in a region of middle frontal gyrus/inferior frontal gyrus for source memory trials compared to old–new trials. A second experiment included delayed, as well as immediate, tests. On delayed trials, the retention interval was filled by one or two intervening trials (up to 36 s) so that the information tested was unlikely to be currently active in working memory (e.g., Cowan, 1999) and thus accurate responding was more likely to require the reactivation, as well as evaluation, of memorial information about the target event (Johnson, 1992; Johnson et al., 2003, Experiment 2). Source memory-related activity in left middle frontal gyrus/inferior frontal gyrus was similar on delayed and immediate tests. That this area was associated with source monitoring judgments across both experiments, regardless of the need for reactivation of the information, strongly suggests that this area is involved particularly in the evaluation of specific information (e.g., perceptual detail) during source monitoring. The present study used the short-term source monitoring paradigm from Mitchell et al. (2004, Experiment 2) to assess potential age-related deficits in the monitoring of specific information.

Method

Participants

Young participants (n = 13 [6 females], M age = 25.0 years [SD = 3.2 years]) were healthy, college students who had not participated in our earlier short-term source monitoring studies. Older participants (n = 13 [7 females], M age = 67.4 years [SD = 2.6 years]) were healthy, independently living adults from surrounding communities. Data from one additional young participant were excluded because of excessive head movement. Young and older adults did not differ significantly on an abbreviated version of the verbal subscale of the WAIS (max score = 30; M_{young} = 24.9 [SD = 3.5], M_{older} = 22.8 [SD = 4.6]) or education level (reported in years, 12 = high school diploma; M_{young} = 15.6 [SD = 2.6], M_{older} = 15.4 [SD = 2.0]) (both Ps > 0.10). Older adults scored high on the Folstein Mini Mental State Examination (max score = 30, M = 29.4 [SD = 0.7]). All participants were right-handed and reported being in good health, with no history of stroke, heart disease, or primary degenerative neurological disorder; they had normal, or corrected to normal, vision; none were taking psychotropic medications. All participants were paid. The Human Investigation Committee of Yale University Medical School approved the protocol; informed consent was obtained from all participants.

Task and design

The procedure followed that for Experiment 2 of Mitchell et al. (2004). During scanning, stimuli were projected onto a screen at the foot of the scanner, which participants viewed through a mirror mounted on the head coil. Each trial was 16 s (see Fig. 1). Participants saw 4 items presented sequentially for 1 s each, which they were told to study for an upcoming test. Two of the items were concrete nouns printed in lower case (*words*); two were black-and-white line drawings of common objects (*pictures*). One of each item type was presented on the left of the screen and one each on the right. Format and location were pseudorandomly assigned so that, across runs, each format/location combination appeared nearly equally often in each ordinal position in each testing condition. After 1 s of unfilled time, a probe word appeared in capital letters. The test probe was accompanied by cues that indicated to the participant which aspect of their memory was being tested (see Fig. 1). Cues were presented in smaller font to the left and right below the probe word. The test types, which were explained in advance to participants, were: *Left/Right* (*LR*), in which the probe always represented an old item and participants were to indicate whether the item represented by the word originally appeared to the left (left-hand button press) or to the right (right-hand button press); *Picture/Word* (*PW*), in which the probe always represented an old item and participants were to indicate whether the item originally appeared as a picture (left-hand button press) or a word (right-hand button press); or *Old/New* (*ON*), in which the probe represented an *old* (previously presented) item or a *new* item, and participants indicated old (left-hand button press) or new (right-hand button press). Half of the trials probed an item from the current trial (*immediate test*) and half of the trials probed an item from one or two trials back (that is, the target could have been presented up to 36 s prior to the test probe, *delay test*). Participants were aware that there would be immediate and delayed tests. The test probe was followed by an 8 s inter-trial interval that included two arrows presented sequentially for 1400 ms each, each

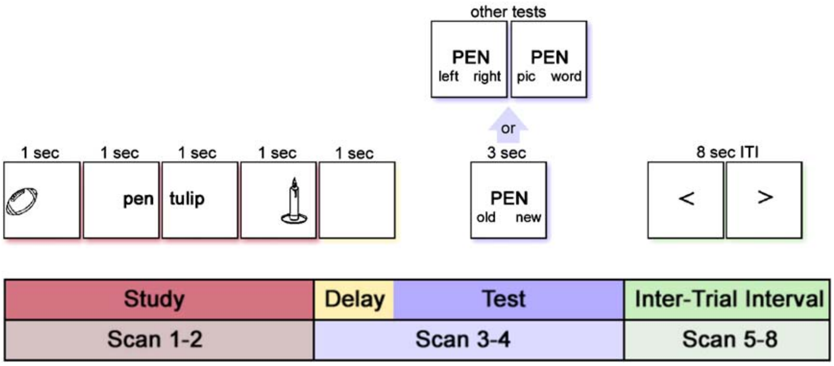

Fig. 1. Procedure and trial timeline.

randomly pointing to the left or to the right. Participants were told that when they saw an arrow, they should push a button with their left hand if the arrow pointed left and with their right hand if it pointed right. The arrows provided a task common to all conditions to allow time for the hemodynamic response associated with remembering and to decrease variability among participants from uncontrolled mental activity between trials.

Stimuli were common objects whose names were 1 to 3 syllables in length (e.g., bell, strawberry, microscope). Pictures were chosen from the Snodgrass and Vanderwart corpus (1980) and similar drawings provided by Friedman (see, Cycowicz et al., 1997). Words were chosen from among the remaining picture labels and additional concrete nouns. For the test probes, names of the pictures were either the original labels or single-word names reached by agreement among the experimenters. Items were equated on various dimensions between conditions on published norms (Cycowicz et al., 1997; Kucera and Francis, 1967; Snodgrass and Vanderwart, 1980; see Mitchell et al., 2004 for details). Across participants, each item appeared equally often for each type of test. Test probes were taken equally often from each ordinal study position, format, and location.

The design was 2 (age) × 3 (condition: LR, PW, ON) × 2 (retention interval: immediate, delay) in which age was, of course, a between-subjects factor and condition and retention interval were varied within subjects. Trials were presented in a pseudorandom fashion, with a different trial order for each participant and parallel order for the two age groups. Each of 5 runs had 8 PW trials and 8 LR trials (4 immediate, 4 delay) and 9 ON trials (3 immediate, 3 delay, 3 new).

Imaging details

The study was run on a 1.5 T Siemens SONATA scanner at the Magnetic Resonance Research Center at Yale University. T1-weighted anatomical images first were acquired for each participant. Functional scans were acquired with a single-shot echoplanar gradient-echo pulse sequence (TR = 2000 ms, TE = 35 ms, flip angle = 80 degrees, FOV 24). The 24 axial slices (slice-thickness 3.8 mm, resolution 3.75 × 3.75 mm in plane) were aligned with the AC–PC line. Each run began with 12 blank seconds to allow tissue to reach steady state magnetization, and was followed by a 1 min rest interval. One volume was collected every 2 s, or 8 full brain scans for each trial; thus there were, for each person, a total of 160 images in each test type × retention interval cell for PW and LR and 120 for ON.

Analyses of behavioral data

Accuracy is expressed as *d-prime* scores. Responses that required a left-handed response (old, picture, left) were coded as targets and those requiring a right-handed response (new, word, right) as lures. Thus, hits (H) and false alarms (FA) could be calculated and converted to d-prime scores. Before calculating d-prime, perfect scores were adjusted as follows: $p(\mathrm{H}) = 1$ was recalculated as $1 - 1 / (2N)$; $p(\mathrm{FA}) = 0$ was recalculated as $1 / (2N)$, where N = the maximum number of hits or false alarms possible (Macmillan and Creelman, 1991). Scores were submitted to an analysis of variance (ANOVA) with condition and retention interval as within-subject factors and age as a between-subject factor. Significant effects were followed up with the appropriate planned comparisons.

Analyses of fMRI data

Data were motion-corrected using a 6 parameter automated algorithm (AIR; Woods et al., 1992). A 12 parameter AIR algorithm was used to co-register participants' images to a common (young) reference brain. Data were mean-normalized across time and participants, and spatially smoothed (3D, 8 mm FWHM Gaussian kernel).

fMRI data were first analyzed using ANOVA (NIS software, Laboratory for Clinical Cognitive Neuroscience, University of Pittsburgh, and the Neuroscience of Cognitive Control Laboratory, Princeton University) in which experimental conditions were directly compared to identify brain regions that had 6 contiguous voxels each showing a significant condition × time interaction at $P < 0.00001$ (Forman et al., 1995). Participant was a random factor, Age (young, older), Run (1–5), Test Type (LR, PW, ON), Retention Interval (immediate, delay),[1] and Time within trial (scans 1–8) were fixed factors. We focused on areas that showed a condition × time interaction; because encoding conditions were held constant, differences between test types should be seen as differences in the fMRI signal during the test period in each trial. Assuming a 4–6 s lag in the hemodynamic response, we further examined these areas for differential age effects by conducting subsequent analyses in which the mean percent change (from time 1) at times 6, 7, and 8 for each participant was submitted to a 2 (age) × 3 (condition) × 2 (retention interval) ANOVA with age as a between-subjects factor and condition and interval as within-subjects factors. Significant effects were followed up with the appropriate planned comparisons.

F-maps were transformed to Talairach space using AFNI (Cox, 1996; version 2.50), and areas of activation were localized using Talairach Daemon software (Lancaster et al., 1997), as well as manually checked with the Talairach and Tournoux (1988) and Duvernoy (1999) atlases.

Results and discussion

Behavioral results

Fig. 2 shows accuracy, measured as *d-prime*. A 2 (Age) × 2 (Interval: immediate, delay) × 3 (Condition: ON, PW, LR) ANOVA showed a main effect of age (*M*s = 2.22, 1.46 for young and older adults, respectively; $F[1,24] = 15.67$, $MSe = 1.45$, $P < 0.001$), main effect of condition (*M*s = 2.28, 1.92, 1.32 for ON, PW, and LR, respectively; $F[2,48] = 17.87$, $MSe = 0.69$, $P < 0.00001$), and a main effect of interval (*M*s = 2.26, 1.43 for immediate and delay trials, respectively; $F[1,24] = 48.88$, $MSe = 0.55$, $P < 0.00001$). There was a significant interval × condition interaction ($F[2,48] = 4.93$, $MSe = 0.40$, $P < 0.05$), with delay having the greatest impact on performance on LR tests (immediate—delay difference = 1.25; $t[25] = 7.87$, $P < 0.00001$) followed by ON tests (immediate—delay difference = 0.76; $t[25] = 3.49$, $P < 0.01$) and then the PW tests (immediate—

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[1] Of course, *new* test items on the ON test were neither *immediate* nor *delay*. Thus, the images corresponding to these trials were deleted from the analysis of fMRI data so that retention interval could be entered as a factor. Both correct and incorrect trials were included in the fMRI analyses because we were interested in the processes engaged in making ON and SM judgments.

delay difference = 0.48; $t[25] = 2.42$, $P < 0.05$). There was a significant age × interval interaction ($F[1,24] = 6.66$, $MSe = 0.55$, $P < 0.05$), because the young adults' advantage over the older adults was greater on the immediate trials (young–older difference = 1.07; $t[24] = 4.88$, $P < 0.0001$) than the delay trials (young–older difference = 0.45; $t[24] = 1.95$, $P = 0.06$).

The age-related differences in accuracy do not appear to be the result of age-related differences in bias, as there were no significant effects involving age in analyses conducted on criterion scores (C).

fMRI results

Only four areas showed differential activity between conditions (PW, LR, ON). Consistent with Mitchell et al. (2004), these included an area of left lateral PFC (middle frontal gyrus, inferior frontal gyrus). As can be seen in Fig. 3, this large area of activation was composed of a smaller inferior portion ($\sim z = -10$ mm to 5 mm) and a larger more superior portion ($\sim z = 6$ mm to 40 mm). Subsequent analyses conducted on percent change at the critical portion of the trial (times 6, 7, 8) for these two areas separately confirmed that only the more superior region showed an age effect.[2] In the more superior portion, there was a main effect of condition ($F[2,48] = 14.95$, $MSe = 0.004$, $P < 0.00001$), an age × condition interaction ($F[2,48] = 5.04$, $MSe = 0.004$, $P = 0.01$), and an age × interval × condition interaction that just reached significance ($F[2,48] = 3.16$, $MSe = 0.002$, $P = 0.05$). As in Mitchell et al. (2004, Experiment 2), young adults showed significantly greater activity on PW than ON or LR trials both immediately and after a delay. In contrast, older adults' activity on PW and ON did not differ at either delay, and both were greater than LR (the triple interaction presumably arises from the fact that, numerically, PW and ON reverse order on delay trials for older adults).[3] The local maximum for this area ($x = -42$, $y = 25$, $z = 24$) is somewhat inferior and anterior to that of the left middle frontal gyrus/inferior frontal gyrus area found to be more active for source memory than old–new trials in Mitchell et al. (2004, Experiment 2; $x = -41$, $y = 6$, $z = 35$), but the extent of the areas identified in the two experiments overlaps considerably. The area found here is also generally consistent with that found in long-term studies of source memory (e.g., Dobbins et al., 2002, 2003; Henson et al., 1999; Nolde et al., 1998a; Ranganath et al., 2000; Raye et al., 2000; Rugg et al., 1999).

The only other area from the condition × time F-map showing a differential age effect across conditions was posterior cingulate gyrus/precuneus (GC, PCu; BA 31, 7; $x = -8$, $y = -55$, $z = 28$; 6 voxels), in which an age × condition interaction ($F[2,48] = 3.86$, $MSe = 0.006$, $P < 0.05$) arose because young adults' activity was greater than older adults' only for ON trials ($P = 0.08$). This is interesting in light of the behavioral data because precuneus activity is often associated with episodic retrieval (e.g., Cabeza et al., 2003a; see Cabeza and Nyberg, 2000, for a review), and posterior cingulate gyrus activity is sometimes associated with retrieval when contextually specific cues are used as probes (e.g., Fujii et al., 2002; Krause et al., 1999). Thus, greater recruitment of this area by young adults on ON trials may signal that they used more specific memorial information to make their ON judgments than did older adults.

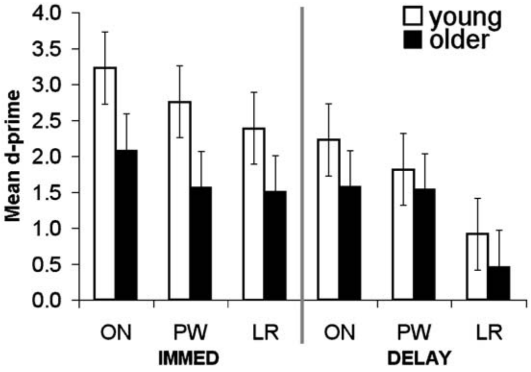

Fig. 2. Short-term source monitoring accuracy (d-prime) for both age groups in each condition.

Interestingly, an area of left fusiform gyrus (GF; BA 37; $x = -43$, $y = -56$, $z = -7$; 15 voxels) showed a main effect of condition ($F[2,48] = 14.79$, $MSe = 0.005$, $P < 0.00001$; PW > ON = LR) and also a main effect of age ($F[1,24] = 9.41$, $MSe = 0.05$, $P < 0.01$; Y > O), but no interactions. The main effect of age is consistent with the possibility that young adults had more format information available at test in all conditions, or at least were more likely to access it, than older adults. It is also possible that this pattern reflects other age-related changes such as reduced use of elaborative visualization of the probes during remembering.[4] An area of left middle temporal gyrus, superior temporal gyrus (GTm, [GTs/LPi]; BA 39; $x = -46$, $y = -62$, $z = 21$; 19 voxels), showed a main effect of interval ($F[1,24] = 3.93$, $MSe = 0.01$, $P = 0.06$; immediate > delay) and a main effect of condition ($F[2,48] = 10.62$, $MSe = 0.01$, $P < 0.001$; ON > PW ≥ LR), but no main effect of age or interactions.

General discussion

Behaviorally, under the current short-term memory conditions, older adults showed poorer old–new and source memory than did young adults. Long-term memory studies often show disproportionate age-related source memory deficits relative to item memory (e.g., Simons et al., 2004; Wegesin et al., 2000; see, e.g., Johnson et al., 1993; Spencer and Raz, 1995 for reviews). This is generally thought to reflect relatively preserved familiarity supporting item recognition and relatively disrupted recollection of specific information. Generally speaking, disproportionate age-related

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[2] The more inferior portion of this large area showed only a main effect of condition ($F[2,48] = 10.56$, $P < 0.001$; PW = ON > LR).

[3] Note that the fact that the SM-ON difference for young adults is greater for the PW than the LR task when delay trials were included replicates Mitchell et al. (2004, Experiment 2). When there were only immediate tests (Mitchell et al., 2004, Experiment 1), LR as well as PW tests resulted in greater activity than ON tests in left lateral PFC. The current finding that older adults show significantly less activity in LR than PW and ON, together with the behavioral evidence that LR performance showed the largest delay-related decrease in both groups, supports the ideas that, for both age groups, format was more salient than location and that location information became unavailable faster than format information. The reasons that this might be the case are unclear from the current data, but one possibility is that LR information was more likely to be encoded in a propositional way than format information in this task, leading participants to be less likely to try to assess detailed information on LR than PW trials.

[4] We thank an anonymous reviewer for this suggestion.

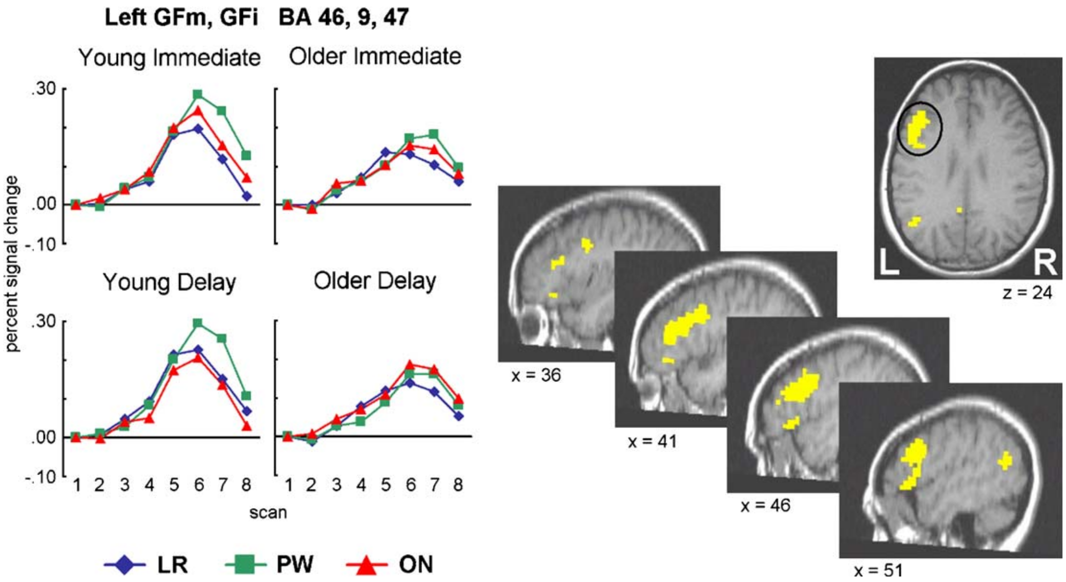

Fig. 3. Left lateral PFC area identified as showing a significant condition × time interaction ($P < 0.00001$, 6 contiguous voxels; Forman et al., 1995). The area of activation is primarily composed of middle frontal gyrus (GFm) and inferior frontal gyrus (GFi), extending into precentral gyrus (GPrC) and posterior orbital gyrus (post GO); BA 9, 46, 44, 45, 6, 47; local maximum: $x = -42$, $y = 25$, $z = 24$; 169 voxels. Associated within-trial timecourses are shown for young and older adults in each condition for the more superior extent of this area, which exhibited an age × condition × interval interaction (see text for details). For the timecourses, the x-axis represents time within a trial (scan), the y-axis represents mean percent signal change from time 1. Throughout the paper, Brodmann Areas (BA) are listed in descending order of approximate size.

deficits on source compared to item memory should be most likely to occur when both age groups rely on familiarity in old–new recognition and use more specific information for source judgments[5] (e.g., Johnson, in press). In the current procedure, however, having source tests randomly interspersed with old–new tests, together with variable delays, may have led both young and older participants to evaluate (or try to evaluate) more specific information, rather than less-differentiated information such as familiarity, on ON trials as well as source trials (see also, Mitchell et al., 2004 for a discussion of task context effects).

We found the expected age-related deficit in left lateral PFC, in an area of middle frontal gyrus/inferior frontal gyrus that overlaps considerably with the source memory-related area found for young adults in Mitchell et al. (2004) and in long-term source memory studies (e.g., Dobbins et al., 2002, 2003; Henson et al., 1999; Nolde et al., 1998a; Ranganath et al., 2000; Raye et al., 2000; Rugg et al., 1999; Slotnick et al., 2003). Like other studies examining age-related changes in PFC function during working memory tasks (e.g., Rypma and D'Esposito, 2000), age differences were seen in the more dorsal extent of this area of activation. Previous research suggests that, for young adults, source memory-related activity in left dorsolateral PFC is associated with the attempt to evaluate specific information, rather than the success of doing so. Increased activity in this general area is found in young adults during long-term source memory judgments for new, as well as old, probes (e.g., Ranganath et al., 2000, though, note that the local maximum for this region was fairly anterior to ours), regardless of response accuracy (e.g., Dobbins et al., 2003), and is similar for immediate and (briefly) delayed short-term source memory tests (Mitchell et al., 2004, Experiment 2; the present experiment). The relatively good performance in the current task resulted in too few trials available for subsequent analysis of correct and incorrect trials. However, the fact that impoverished activity was concomitant with decreased mean accuracy in older adults is consistent with the idea that at least part of the age-related episodic memory decrements shown in the literature may be due to deficits in engaging this area to monitor specific memorial information. Further evidence that directly links decreased activity with decrements in performance is needed to confirm this speculation. Likewise, more data are necessary to ascertain whether this deficit reflects age-related differences in what information was encoded, what information was revived and evaluated in the service of making source memory decisions under these circumstances, or age-related neurophysiological dysfunction that limits the full recruitment of this area or its efficacy once engaged. For example, age-related differences in activity in fusiform gyrus might suggest that older adults had less source-specifying information available (perhaps because of age-related binding deficits; e.g., Chalfonte and Johnson, 1996; Li et al., 2005; Mitchell et al., 2000a,b; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2004; O'Hanlon et al., 2001), or were less likely to access it, than young adults. It may be that older adults are less likely to attempt to evaluate specific information if they do not feel that they have it.

It is interesting that the local maximum for the area of left PFC showing an age-related deficit in source-related activity is within two voxels of the local maximum of an area we previously found to show an age-related deficit when participants were asked to briefly *refresh* words that had been read just 500 ms earlier but that were no longer present (Johnson et al., 2004). Exactly what

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[5] An interesting corollary is that the extent to which one finds age-related deficits across different types of source identification tasks may depend on the specificity of the information required to accurately perform the task. For example, source tasks that can be carried out using relatively less differentiated information such as a sense of "goodness or badness" may show less striking age effects than those that require more specific information such as perceptual details (e.g., Rahhal et al., 2002).

the relationship is between these two findings needs further investigation, but it might reflect the fact that both refreshing and source monitoring involve foregrounding specific aspects of representations.

It is worth noting that older adults sometimes show compensatory brain activity (greater activity in some area than young adults) for complex tasks, often in regions contralateral to those in which the older adults show dysfunction (e.g., Cabeza, 2002; Cabeza et al., 2002; Gutchess et al., 2005; Reuter-Lorenz, 2002; Reuter-Lorenz et al., 1999). We did not find any PFC activity that might reflect compensation for the age-related deficit in left PFC activity, even after lowering the threshold for the CxT to $P < 0.0001$, 6 contiguous voxels (although at this threshold an area of right GFm [BA 9, 46; $x = 50$, $y = 17$, $z = 36$] did show a main effect of age, young > older). When older adults' data were analyzed separately and thresholded at $P < 0.001$, we still found no evidence for compensatory PFC activity. It may be that we did not find age-related compensatory areas in this study because the procedure reduced explicit encoding and remembering strategy differences between age groups compared to more complex long-term memory studies (see also, e.g., Johnson et al., 2004; Stebbins et al., 2002). Another possibility is that compensatory activity is less likely for the monitoring processes tapped in this procedure than for the rehearsal or retrieval processes likely to be engaged in most working memory and long-term memory tasks. Comparison of immediate and delayed short-term source memory and longer-delayed long-term source memory tasks in the same young and older adults would be informative in this regard.

In any event, the general lack of right lateral PFC activity in this study converges with the findings of Mitchell et al. (2004) to question the proposal that right PFC activity reflects monitoring of memorial information of all types (e.g., Cabeza et al., 2003b; Rugg et al., 2003). Rather, the data support our previous suggestion that the pattern of activity observed in left and right lateral PFC depends, at least in part, on the qualities of mental experiences that are being evaluated (Johnson and Raye, 1998; Mitchell et al., 2004; Nolde et al., 1998b). This, in turn, is likely to depend on specific task demands (e.g., ON vs. PW judgments) and on the overall task context, such as whether participants are encouraged to utilize more- or less-differentiated information (e.g., Mitchell et al., 2004). These patterns are likely to vary also across groups (e.g., young and older adults) to the extent that different classes of information are more or less available to be evaluated or are presumed by participants to be more or less diagnostic in making a memory judgment.

In conclusion, the present study replicated the findings of Mitchell et al. (2004), showing that left dorsolateral PFC activity is related to the monitoring of specific memorial information during remembering in the short-term as it is in long-term memory studies. It extended those findings by demonstrating an age-related deficit in this region that could account, in part, for age-related source memory decrements.

Acknowledgments

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